Crowdsourcing information via mobile devices as a migration enabler towards the SmartGrid

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***Abstract*—The high penetration of mobile devices is an indicator showing their impact to our daily life, witnessed via the diverse services offered through them. In the energy domain they can be used as a tool for bidirectional communication between the energy prosumers and the other envisioned actors in the SmartGrid. Most trials today require additional hardware installations at user's side in order to collect metering data and use it for energy optimization; however similar information can be acquired from the users and in many cases the quality of information may be comparative or better than the passive methods applied today (especially when considering estimated future user behavior). We believe that mobile devices can play a key role in user-assisted data acquisition and prediction, as well as empower approaches dealing with analytics, what-if simulations etc. In this capacity crowdsourcing energy information via the use of mobile devices can serve as an enabling technology until the SmartGrid and its services are fully deployed. We present here the key envisioned ideas, an architecture as well as a prototype implementation for their realization.**

I. Introduction

The vision of SmartGrid is promising a more versatile and intelligent network of collaborating actors that will eventually lead to better utilization of its resources, better management and of course will enable us to achieve goals such as energy efficiency. Significant effort is put together in order to set not only the vision, but also specify a roadmap that would incrementally lead to its realization [1] [2]. It is already clear that such an approach will have to heavily depend on an information infrastructure and attach itself to the existing Internet services, Internet of Things as well as enterprise applications [3]. The high penetration of advanced mobile devices such as the tablets and SmartPhones provides new opportunities towards directly including end-user preferences and information related to his energy signature. This information can be either measured and conveyed by the mobile device or even assessed depending on the user's context (e.g. his calendar) and future plans.

As users in the SmartGrid era will be able to not only consume but also produce energy (hence called prosumers), the dynamics and complexity of the system increases. Being able to use information and communication technologies may provide an insight on the prosumer current and future activities that is not possible in the conventional grid. As the future energy monitoring and management system will be in close cooperation [4] with the enterprise systems, enterprise services will integrate information coming from highly distributed smart metering points in near real-time, process it, and take appropriate decisions. The decision making process can consider prosumer-specific behavioral information either measured, assumed or explicitly provided by the prosumer. This will give rise to a new generation of applications that depend on "real-world" services which constantly hold actualized data as they are generated. Furthermore the integration of potential future behavior of the prosumer may enable better correlation and analytics. This crowdsourcing of information via bidirectional mobile communication with the prosumer, which relates to his infrastructure, planned activities and current context may provide us with not only better understanding but also future knowledge that could be considered in future energy management and decision support systems.

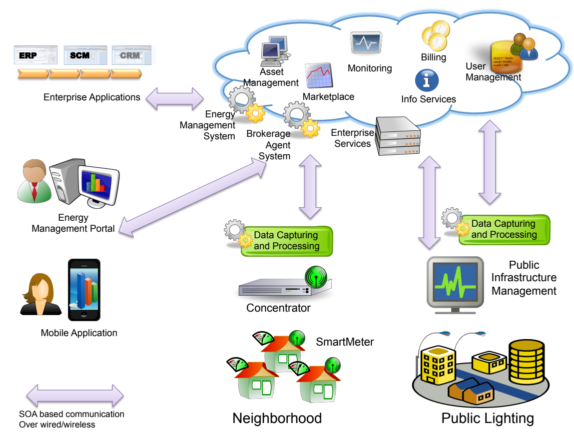

Fig. 1. Energy enterprise services and information flow

The NOBEL project (www.ict-nobel.eu) develops an approach for smart city neighborhoods that enables such information acquisition from the infrastructure and the end-user (as depicted in Fig.1). The enterprise system is comprised of several Internet-accessible services which, in their turn, can be used to create mash-up applications. Additionally, following a software-as-a-service (SaaS) model, we expect the rise of new applications (as well as feature enhancement) by simply rapidly combining cross-enterprise services to deliver customized functionality. Envisioned services include: energy monitoring, billing, asset management, information services, marketplace etc. Since all of the services will run in the cloud, and may be hosted on various servers, we consider at design time open interfaces accessible from anywhere via the web including mobile devices. Lighweightness, universal access, and performance have led us to follow the REST principles towards designing these services. As such, it is expected to obtain an easier integration, better flexibility and higher performance than the typical SOAP-based web services.

II. Building Prosumer Communities

Today most efforts involving end-users in the SmartGrid focus on individuals, which in our opinion may have limited impact due to uncoordinated reactions, degrading interest over time, high expectation on continuous user involvement etc. We believe that what could unleash the true power of SmartGrid would be the consideration of prosumer communities i.e. multi-level groups of users and their assets [5]. Focusing on communities will definitely give the critical mass to have some impact on any transaction envisioned in the SmartGrid era, as these can act as Prosumer Virtual Power Plants (PVPP). Such PVPPs are able to adjust their consumption or production e.g. by rescheduling internal activities. Large enough prosumer groups may have impact comparable impact to small industrial facilities, hence the necessary critical mass.

Prosumer community member interactions may lead to the emergence of more intelligent global behavior, unknown to the individual members. Typical example from the math and computer science domain is the swarm intelligence; the collective behavior of decentralized, self-organized natural or artificial systems. Since the SmartGrid is seen as a very complex system of systems, emergence i.e. the way complex systems and patterns arise out of a multiplicity of relatively simple interactions, is of extreme importance. Potential goals such as prediction of prosumer group's energy behavior may assist in better planning and achieving targets such as energy efficiency. Additionally from the economic domain we have a perspective on how behavioral attitudes depend on incentives and expectations, while from the social science we get insights on interactions among communities and populations. Since the SmartGrid domain is not only a multi-disciplinary one but will also be driven by multi-dimensional networks operating over a sophisticated cyber-infrastructure, integrating lessons and ongoing research targeting highly interconnected communities [6] may be of help in understanding the complex emerging phenomena.

As depicted in Fig.2, Prosumer Virtual Power Plants (PVPP) could be realized by integrating distinct communities of users with high flexibility towards altering their energy signature. Similarly a user may take part in several communities, while devices such as electric cars or common appliances in house may even be federated. Communities will interact with eachother and possibly be part of other larger communities or interact with coordinating entities. The result is a very dynamic ecosystem of cooperating SmartGrid actors each of which is striving towards achieving his goals.

The existence of heterogeneous communities could enable the emergence of third party service providers that would serve/assist such communities and adopt new roles in the

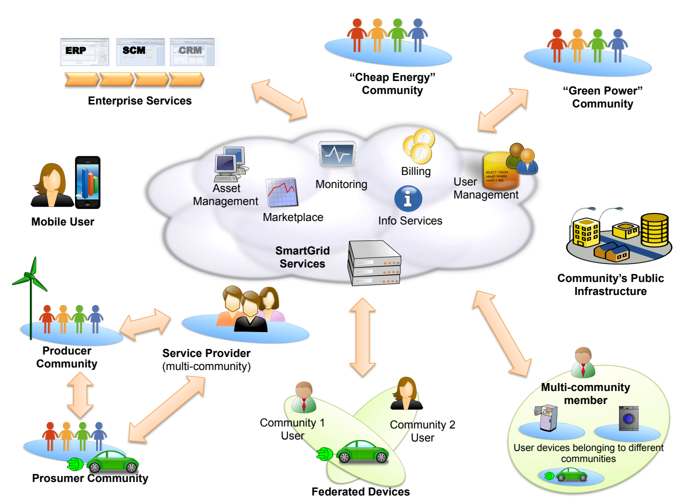

Fig. 2. Prosumer community empowered SmartGrid

energy domain. Similarly for the prosumer participating in such communities, more benefits might be achieved, as he is acting as part of a group in comparison to acting alone in an uncoordinated way. A community of thousands users offering their electric cars to be charged at any time, may offer a service to the network for storing excessive energy, or even buy energy based on cheap/negative prices [7] in the energy market. Similarly on a high demand time they could feed-in energy in the network, acquiring monetary benefits for the members. Impact is the key, and consideration of communityware SmartGrid can provide the critical mass to achieve it.

III. Enabling Prosumer Active Participation

In order to realize its full potential, the SmartGrid vision addresses the integration of prosumers and depends on their active participation into the new information driven infrastructure. The first enabling step is to allow for almost real-time acquisition of metering data; to this end several smart metering projects are underway in Europe and the world. However that is not enough. The users are envisioned to be able to adjust their behavior depending on external impulses such as a price variation (e.g. stock-exchange like behavior) and even trade prosumed energy in online marketplaces.

Several investigations try to figure out how the user will be connected to the information side of the SmartGrid, and concepts are tried out ranging from energy-provider driven home gateways, integration with existing Internet connections, or even over the still evolving next generation of mobile network. When looking at the penetration rates of mobile phones and especially the trends for the SmartPhones, as well as the plans for the mobile infrastructure one assesses that this is the most promising approach that has the capability of offering direct connection of the end-user to the information side of the SmartGrid.

In the last years we have seen the emergence of various online service-driven approaches that heavily depend on user-provisioned content. The social networks such as Facebook, Google+, YouTube, Twitter etc. enable the users to interconnect and share information at an unprecedented scale; information that would have been impossible to acquire and would be very costly to do with any other means. Although most of such information is still unstructured, and relevant only for specific target groups and possibly with little general business value, one can still find innovative approaches that when collecting huge amounts of them may generate a business benefit e.g. targeted advertising.

What online services coupled with mobile devices can offer is an "always-on" end-user that actively provides content fed to these services (whether he actually is entering data or the data is passively collected from his context e.g. location without him directly interacting). Crowdsourcing [8] has emerged the last years as an approach where the user-provisioned information in large scale and when properly processed may provide accurate (and invaluable in business) services. These may range from polls, trend identification, real-time sensory information integration etc. As such, integrating the SmartGrid prosumer via mobile devices may pave the way for new innovative energy related services as well as enhance existing approaches [9].

There are several scenarios where user-provisioned data coupled with mobile services might be of interest to investigate, however we focus towards the following areas:

- Profile analytics
- User-assisted prediction
- What-if simulations
- Migration towards active Demand-Side Management

From the aforementioned scenarios, a direct connection for monitoring and possibly control of the associated energy prosuming devices is beneficiary but not mandatory. As such these scenarios can still provide significant benefits during the migration towards the fully envisioned SmartGrid. General crowdsourcing platforms in the future [10] may enable the easy build of sophisticated applications, and the energy domain may provide the perfect large scale set-up needed and have a real impact on our efforts to tame the emerging SmartGrid-considered problem areas.

A. *Profile Analytics*

Modern mobile devices such as SmartPhones and tablets have an increased amount of sensory (e.g. GPS) integrated as well as access to user's activities (e.g. daily schedule, social network connections, location etc.). As such not only they can convey smart metering data, but also assess user-related information e.g. its context and possibly correlate it with activities and expected user behavior. In a typical scenario they can act as gateways for smart meters towards online metering platforms that are not under the control of the energy provider (who needs the info for billing). As such energy consumption or production could be reported to online services that may provide analytics to the user or communities of them. For instance such a service could be an aggregated view on how energy efficient a neighborhood is compared to similar districts in the same or other cities. Even for the user this could mean that he would be for instance able to assess her carbon footprint, get customized tariffs that better match his behavior etc. In another scenario driving with her electric car a user may be dynamically guided to the cheapest place to recharge the car or even adjust the route to match multiple goals such as car's batter, user's meetings, traffic impact etc. Similarly value added services can be provided, assuming for instance that more detailed information is available on the actual energy prosuming devices. For instance by evaluating the usage and energy signature of a washing machine an online service may provide an analysis showing that it is worth investing in a newer but more energy efficient washing machine as the price of acquisition could be covered in a couple of months due to lower consumption.

Today we are not able to do this kind of analytics, mainly because we do not have access to the fine-grained data, and even in the rare cases that some do (e.g. via the electricity metering company) these are either unwilling or it is too cumbersome to provide them to third parties. However with mobile devices the user may find it easier to publish his data to online services in an automatic way similar to what is doing today on social networks. For the latter to happen we need though open communication systems and interoperable services to be able to do the gathering and evaluation of huge amounts of data online. We are confident though that when the first hurdles are overcome this might lead to new insights for the prosumer, the enterprises and the society.

B. *User-assisted prediction*

Access to energy data is today cumbersome for end-users. As such analytics can be done only for large groups of consumers, in order also to normalize any deviations at single level. The aim is to be able to predict energy consumption and production in order to take the necessary demand response actions. While this might work at a satisfactory level for very large groups, it has several deficiencies e.g. can not predict accurately enough the individual user behavior and as such fine-grained customization for a specific user is difficult. Additionally dynamic changes such as effects of user-behavior can not be considered (or are integrated with a significant delay) in real-time models.

Mobile services may assist towards better understanding the behavior of the user as well as gather actively or passively information about his environment that may have an effect to his energy signature. Typical examples would include identifying the devices the user has as well as their operational schedule; this can be done either manually (entered by the user) or automatically (dynamic discovery of devices and their status is possible). User specific models fed with this data may provide a more accurate prediction of the user's prosumption, while coupling it with automatic means and other available information (e.g. personal schedule) can only enhance the quality of information acquired and used. Apart from the obvious benefits for the user, preprocessing of data at such fine levels and aggregation may enable far better dynamic prosumption prediction models and real-time simulations.

C. What-if Simulations

The majority of existing simulations consider what-if scenarios in order to see the macroscopic effects of events in a large complex network such as the electricity grid. Apart from security of supply and some energy-provider benefits, simple users do not have the capability of running such scenarios at fine-grained level. The only thing offered today by some energy portals is the prediction of the overall costs based on mostly static tariffs which is very limiting.

Assuming that the user may identify devices and their schedules with the assistance of the SmartPhone he can run what-if scenarios with multiple varying in time tariffs, as well as varying devices and associated schedules and see the impact to his energy signature. This microscopic analysis enables the user to experiment with simple what-if scenarios and take decisions that fit with his needs and plans. Such scenarios would answer questions such as: what if I reschedule the washing machine for this time frame? What if the electricity price changes ? What if I invest in a solar panel? etc. From the social side we consider this kind of enabling tools very significant, especially in the migration path towards SmartGrids where the user wants to evaluate the real benefit of energy decisions he makes prior to enforcing them and decide on the best strategy fitting to his goals.

D. Migration towards active Demand-Side Management

Being able to do active demand-side management by integrating the end-user infrastructure is one of the core visions of SmartGrid. This implies automatic adjustment of the user's infrastructure which would mean not only being able to turn on/off devices, but also adjusting their schedules as well as their behavior during operation. To achieve that however many aspects especially towards interoperability, service-oriented infrastructures, capturing and understanding of energy states and their impact on processes as well as restrictions by the overall goals etc. need to be better understood. Their impact in a global ecosystem such as the SmartGrid needs to be assessed at multiple levels. Until this fully self-managed infrastructure is in place, we need migration paths towards it. The SmartPhones coupled with the user interactions may be able to assist in that.

In very simple scenarios, real-time urgent notifications can be pushed to the device and depicted to the users who can then assess them and take the necessary control operation e.g. reschedule some activities, turn devices off etc. However due to the high burden on the user, we expect that the mobile device may act as an intelligent gateway and control the residential devices (in a standalone or in collaboration with other in-house systems). Price signals attempt to convey similar messages via the electricity cost, however cost might not be the only differentiating factor. Having a direct communication channel to the prosumer that can be used not only by the energy provider but by any entity (e.g. a social networking service) one can clearly see that multi-faceted energy related issues and group actions may be propagated effectively easing the creation of the prosumer communities.

IV. Demonstration Application

We have considered aspects of the aforementioned scenarios and drafted an architecture that would enable us to partially realize them. The main motivation is to clearly depict how the mobile user can interact with Internet hosted services which are coupled with an enterprise system. Our goal is to provide the bidirectional communication with the prosumer, and enable the realization of what-if scenarios. The data collected can be used for profile analytics and user-assisted prediction, however the current prototype design only partially touches these. As we follow the "software as a service" (SaaS) all services are hosted in an online service platform. An overview of the main architecture components is modeled in FMC (www.fmc-modeling.org) as depicted in Fig.3.

A. Architecture

The mobile user interacts with an application installed in his SmartPhone (or Internet-connected tablet). The initial installation of the application is supposed to happen simply by downloading it from an online application store. This is expected to be an energy provider customized application but it can also be a general energy mobile application that would allow connections to multiple energy providers. This is expected to be similar e.g. to what is found in the mobile banking industry domain and is not within the scope of our research here. The mobile application hosts much of the logic for processing and depicting data (therefore relieving the enterprise systems of such tasks). It also has some local DB for storage (replication) of data, which will be partially synchronized with the backend system provided that a connection is available (opportunistic communication & synchronization).

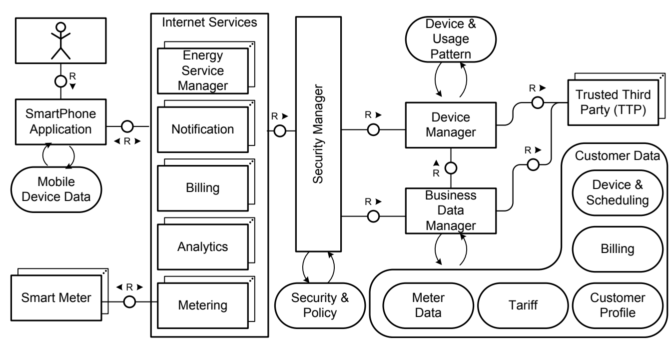

Fig. 3. Model of the main architecture components

The interaction with the enterprise system is via several Internet hosted services e.g. energy service manager, notification, billing, metering etc. All of them are able to communicate via well defined interfaces (in our case following the REST architecture style). As such there are no hard interdependencies which means that they can also be deployed in several (distributed) servers if it is required to do so e.g.

for availability, scalability, or performance reasons. In our architecture we can distinguish:

- *Energy Service Manager*: This is the main point for interacting with the energy services. This includes for instance management of the user's data/devices/tariffs etc.
- *Notification*: The notification component is mainly for bidirectional user interaction. Its major role is to enable the event-driven notification of the user from the enterprise side. This could include alarms, scheduling maintenance in his infrastructure, tariff promotion, advertising, provision of value added services etc. Additionally it can be used by the user to report problems or pose questions from his side.
- *Billing*: This provides a billing overview to the user, as well as enables interaction with other services e.g. the payment service.
- *Analytics*: Providing analytics on the user profile, as well as his behavior is of key importance. This component enables the processing of historic and current (including devices and their schedules) data and provides insights (e.g. current/expected prosumption) for a single user (of interest to the mobile user) or groups of users(of interest to energy provider).
- *Metering*: This is used by the real devices to report real consumption or production on the user side. For instance a photovoltaic panel reporting the energy produced or a meter providing user's current consumption. Additionally it provides upon request data to the client applications e.g. for graphically depicting them.

All of the services provide the respective data, however the representation of them is under the responsibility of the mobile device and its capabilities. Additionally we can see on the enterprise side:

- *Security Manager*: for all of the Internet services available for interaction, a built-in security check is done for authentication of the user and a policy check for authorization of each transaction.
- Device Manager: as implied by the name this component manages all data related to the devices as such including their usage patterns. These data are expected to be made available from the device manufacturers and describe the operational states and energy consumed/produced under various states & conditions. This info is complemented with data coming from different countries or groups depicting normalized values for the scheduling of such devices e.g. in average household. The device manager can actively contact external services in order to acquire these two categories of data (or accept push from authorized manufacturers and service providers). The combination of both is expected to provide a very good approximation of the device behavior.
- Business Data Manager: this component is responsible for managing all customer related business data. As seen in Fig.3 this implies custom user devices (not covered by the device manager DB), custom user scheduling (adjustment to the standard ones), invoices and payments, tariffs, metered data, profile information etc.
- Trusted Third Party (TTP): Collaboration with infrastructure and/or other third party trusted services is required. Example such services include e.g. the update of device's energy signature from the manufacturer, the country/region normalized device scheduling profile, security services such as Online Certificate Status Protocol (OCSP) or Open Authorization (OAuth) etc.

B. Implementation

An initial implementation was done in order as a proof of concept. On the server side, there are REST services implemented in Java with the Jersey framework (jersey.java.net), providing the envisioned functionality. The data is stored on a mySQL DB (www.mysql.com). On the client side we have selected the android 2.3 platform (www.android.com) to experiment with. The interaction with the server side is done by calling the available RESTful web services on the server side. Similarly on an event-based mode notifications are pushed to the mobile. Considering potential performance bottlenecks, we have decided to use the Google Protocol Buffers (code.google.com/apis/protocolbuffers) which offers a simple API and high performance [11] serialization format with an interface description language.

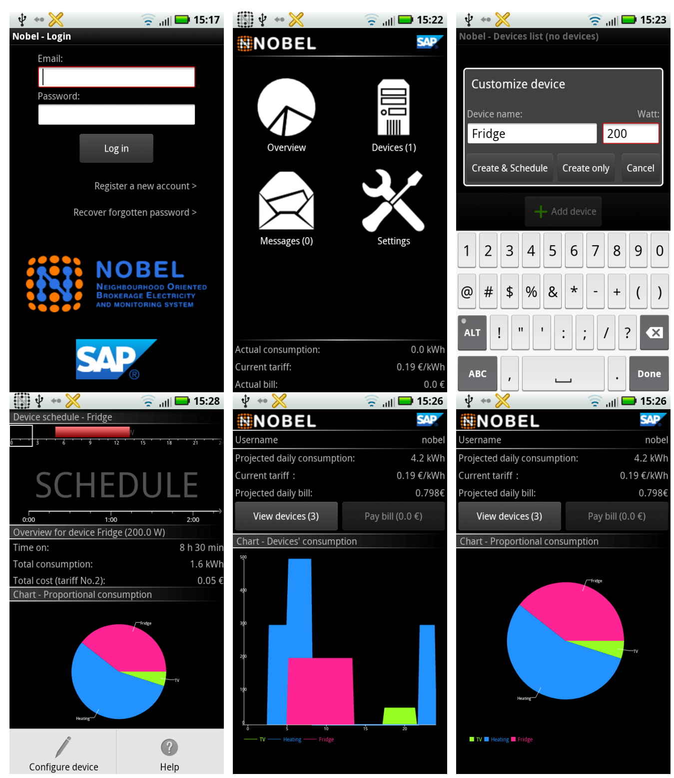

Fig. 4. Prototype implementation in Android

A view on some of the implemented functionality is depicted in Fig. 4. The user has an overview of the consumed energy, as well as information on his current active tariff. Additionally at the bottom of the screen a graphical representation provides a holistic view on the energy footprint with respect to consumption, production and their delta. This can be further broken down to the specific prosumption devices active on behalf of the user. Additionally by providing the capability to add/remove/modify devices and their schedules, the user is able to see how his energy footprint is affected and run what-if scenarios.

C. Future Directions

Our initial prototype has implemented a subset of the functionalities envisioned, hence, still many issues are remaining and existing ones could be enhanced. The performance and scalability are open issues that will need to be adequately assessed. Apart from the obvious security impact, the number of the users as well as the actions they perform will have distinct impact. As such it will be interesting to further investigate these patterns, the impact they have on the Internet services and the business components and develop a strategy for load balancing of those.

Additionally an equilibrium will need to be found for the dilemma of the amount of data that can be processed on-device vs. performance and/or user-tolerated application responsiveness time. Clearly from the enterprise side there is a wish to minimize the amount of on-demand computation (e.g. when calculating single-user real-time analytics) and delegate that to the device. The last is done by providing access to information e.g. for real-time billing view accessing the tariff and energy usage and let the mobile device calculate the estimated amount that needs to be paid would be enough. However any computation on the device depends heavily on the availability of memory and CPU power which varies generally (although several modern SmartPhones feature already high-performance dual-core CPUs). So the impact of local vs. in-network computation needs to be further investigated. The same train of thought applies to other issues such as the synchronization with the server (how often, selection of data, etc.), the interactivity and refreshing of the GUI on the mobile side with respect to the resources consumed etc.

Assuming that the detailed profiles of the users are available as envisioned, one could develop the respective models for trend detection. This would greatly complement the prediction of energy prosumption and would represent a valuable tool especially for the migration period towards a fully supported SmartGrid infrastructure. However due to the amount of information shared, privacy preserving mechanisms will have to be in-place at the prosumer side as well as at enterprise side that facilitates exchange of information with other service providers. Privacy and the appropriate level of trust is an active research area for the SmartGrid.

V. Conclusion

We have presented the key motivations and the main thrust of ideas towards using the ever increasing number mobile devices to tap into crowd wisdom in order to acquire high-quality energy information. This information does not restrict itself to smart metering data but also current and expected prosumer context information that may enable us to build better decision support systems that integrate future knowledge about the prosumer or the communities he participates. The prosumer gets not only real-time information but has also the ability to run what-if scenarios and hence better select his future strategic decisions with respect to energy prosumption.

Contrary to approaches that require hardware installations at user's side, our approach does not require the provision of a gateway for integration but relies on various sources of data such as device's energy signature, device's scheduling for a specific country or location, the customized usage (scheduling) by the user etc. Hence it can be used during the migration phase and assist the users as well as the utility until a full-blown monitoring and control SmartGrid infrastructure is in place. We believe that this may assist towards better estimating future energy prosumption since explicit information is given by the user for his future behavior. In addition to the main driving forces, we have presented an architecture and a prototype implementation to show how such functionality could be realized.

Acknowledgment

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