Informatics Solutions Requirements for Electricity Consumption Management

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Our work is supported through a grant research project within PNCDI III competition that aims to transfer the knowledge and expertise from universities to business environment in order to improve the performance of modern technologies. The scope of our project PN-III-P2-2.1-BG-2016-0286 is to develop informatics solutions for electricity consumption analysis and optimization in smart grids. The new technology that belongs to our partner Repower Furnizare Romania SRL - electricity supplier consist in pilot smart metering system recently implemented at consumer site. In this paper we describe the smart metering system technology, informatics solution requirements, our research objectives, main software technologies and prototype architecture.
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1 Introduction

The proposed informatics solutions are particularly important in the current context of the European and national regulations regarding large scale implementation of smart metering systems(SMS) [1], [2], Internet of Things (IoT) concept, reduction of carbon footprint and improvement of energy efficiency [3]. In order to implement SMS, the National Regulatory Authority for Energy (NRAE) approved national targets for grid distribution operators that should be reached until 2020 (up to about 80% of final consumers should have smart meters, based on cost benefit analysis).

Comparing with previous period before SMS implementation, the final consumers and prosumers play an active role. They are more aware of consumption aspects due to new technology benefits such assmart metering applications. The volume of data provided from *SMS* and intelligent appliances (IoT) is significant and currently it is not processed. Compared to conventional electricity meters that are manually read once a month, the SMS measure aggregate/individual electricity consumption of IoT appliances at configurable time intervals (5, 10, 15, 30 min).

In this area, at international level there are researches and studies for data management described in [4], [5],[6] but at national area there are no tested or validated solution. Also, *prosumers* profiles are described in [7], [8], [9], but due to national aspects (legislation, market requirements, consumer's necessities, demographic and infrastructure constraints), these solutions cannot be directly applied in Romania. As for the optimization models there are several approaches at national level [10], [11] and international level [12-16] and some electricity consumption forecasting models are described in [17-21]. Also, there are several *business intelligence* platforms developed for the power grid companies [22], [23]. However, these solutions require advanced customization and investments in order to be directly applied in Romania.

2 Smart metering systems

SMS measure individual electricity consumption of IoT appliances (such as cooling, ventilation, lightning systems, etc.) at configurable time intervals (5, 10, 15 minutes). These record on each phase: voltage (V), electric current (A) and phase shift between voltage and current (ϕ). Then active power (W), reactive power (VAr), apparent power (VA), power factor, active energy (Wh), reactive energy (VArh), apparent energy (Vah) and ratio between power and energy that is in/out the meter, could be calculated. SMS allow bidirectional measuring for prosumers that own solar panels, wind/biomass/diesel generators that can cover their consumption and send the surplus to the grid.

The gateways collet data that come from SMS and ensure that the data is sent to the local database. The access to the gateways is performed by web interfaces that allow the connection of any device: PC, laptop, mobile phone, tablet, etc. Data transmission is ensured by the two communication ways: PLC (Power Line Communication) and radio waves (485, 868 MHz). The main characteristics of the gateway are: open operating system (Linux), local memory (SD card) up to 32 GB, 2 LAN RJ45 with different IPs, integrated Wi-Fi, multiple communication ways (PLC, 485/868 MHz, ZigBee) and USB. Interconnection elements also known as fittings (PLC/485 bridge, 868/485 bridge, router 3G/Wi-Fi, etc.) allow the conversion of the signals and connection of the devices. Sensors are devices that record electrical and environment data (such as temperature, humidity, luminosity). Other devices include those devices whose communication protocol is known and use the data transmission management via PLC, Ethernet, radio waves, Wi-Fi, Bluetooth, etc.

3 Research objectives at glance

The main objective of the project is correlated with our partner current necessities to implement a pilot smart metering system and energy efficiency measures. Our target is to perform a business intelligence informatics prototype that will allow our partner to provide its electricity consumers with online platform for consumption management. This platform will allow our partner to monitor, process and analyze in details or aggregately the electricity consumption. The specific objectives are the following:

Developing data management model. Large volume, velocity and heterogeneity of data from *SMS* /*IoT* appliances require a model for data processing and integration. Our original contribution consists in a data mapping model that integrates structured data from *SMS* into a relational database and semi/un-structured data from *IoT* appliances into a *NoSQL* database, centralized at the electricity supplier level for performant and real-time analysis.

Developing dynamic profiles. The active role of the *prosumers* will lead to impossibility to use the existent profiles [6] and their continuously changing behavior requires adaptive and dynamic models for determining their consumption/production profiles. Our contribution consists in developing profiles and consumption/production patterns based on *data mining* (clustering, classification) and *artificial neural networks* (self-organizing maps).

Electricity consumption optimization. On one hand, flattening of the daily load curve is important for grid operators due to the fact that power plants are less required to vary their output. It also has direct repercussions on electricity grids loading, by eliminating or postponing onerous investment in electricity grids. On the other hand, final consumers such as households or retailers are interested in minimization of electricity payment. Therefore, there are two different approaches that can be treated in terms of electricity consumption optimization. Our contribution consists in developing electricity consumption models with different objective functions. We'll model the conventional and *IoT* appliances and study the effect of *prosumers'* generation sources and storage equipment on electricity consumption optimization. Based on [24], the electricity consumer can save up to 50% of the electricity payment as a consequence lower (by 30%) off-peak electricity price compared to the peak electricity price. Then, we will model and size storage equipment that would further improve the results of the consumption optimization process.

Electricity consumption forecast. We'll propose models for consumption forecasts on different time horizons. Because there is an autoregressive component of total consumption, we will develop algorithms based on autoregressive neural networks and stochastic methods [21]. Based on high accuracy consumption forecast, the electricity supplier will be able to efficiently prepare bids on the electricity markets and better plan other resources. Also, the setting of advanced tariff systems is based on both consumption profiles and forecasts.

Development of interfaces for advanced analysis of consumption data. Electricity *prosumers* need mobile interfaces and applications to monitor their behavior. Also, the electricity suppliers require intelligent platforms to analyze aggregate/detailed consumption and find out new trends in the *prosumers'* behavior based on *SMS/IoT* data. Our contribution consists in developing the *business intelligence* platform in a *cloud computing* architecture that allows: *prosumers* to configure, schedule, control and monitor their appliances and electricity suppliers to analyze, plan and forecast the aggregate/detailed consumption.

The feasibility of the project is facilitated mainly by our experience in interdisciplinary related projects [25], [26], by the cohesion of the team members and also by the collaboration with *Repower Furnizare Romania SRL* (electricity supplier) that agreed to support our initiative and provide access to their pilot data, so that we will build the models on real *SMS/IoT* data recorded at the retailer site. In this respect we have their written agreement. However, we plan to build a *SMS/IoT* environment so that we'll be able to test and validate the proposed models.

4 Informatics solutions requirements

The data volume generated by the smart metering systems can be significant and can yearly totalize millions of records for one single retailer. These data could be processed by Big Data solutions in order to improve the performance of business decisions of electricity supplier, bring new opportunities to electricity consumers, grid operators and suppliers.

The informatics solutions for the consumption management that will be developed within this project will allow:acquisition, extraction and visualization of data that comes from out of the smart metering systems; building the dynamic individual and aggregated consumption profiles; optimize electricity consumption and program the operation of electricity individual appliances that could minimize the electricity invoice and/or minimize consumption peak, efficient consumption, reduce pollution by promoting local renewable sources and allow sustainable development; identify based on individual consumption those energy intensive appliances and propose measures in order to increase the efficiency or replace them; reduce the electricity consumption and implicitly the carbon print; real time advanced analyses based on SMS data that should support strategic decisions, including consumption forecasting that is necessary for electricity market bids and performant tariff system design; perform real time, dynamic and statistical analysis of consumption data and view graphical trends and access reports.

5 Prototype architecture

Based on the above mentioned objective, we proposed a detailed architecture of the prototype with the following components (**Fig.**1):

- Data level – it includes a physical layer for the data sources gather from the SMI/IoT devices, an Extract, Transform and Load (ETL) process that extract the data from sources and load it into relational database, a central database that organize data and a data warehouse that enables multidimensional analysis for energy supplier's management team;

- Models level – it includes algorithms for prosumers' profiles determination, consumption optimization and forecasting. This algorithms will be developed, tested and validated based on the data organized into the central database;
- Interfaces level – it includes visual analytical tools for data analysis through dynamical charts, pivot tables, narratives, dashboards, selections. The dashboards will be developed with Business Intelligence tools that allow drill-down, roll-up, data rotations and sections specific to OLAP (On-Line Analytical Processing) technologies.

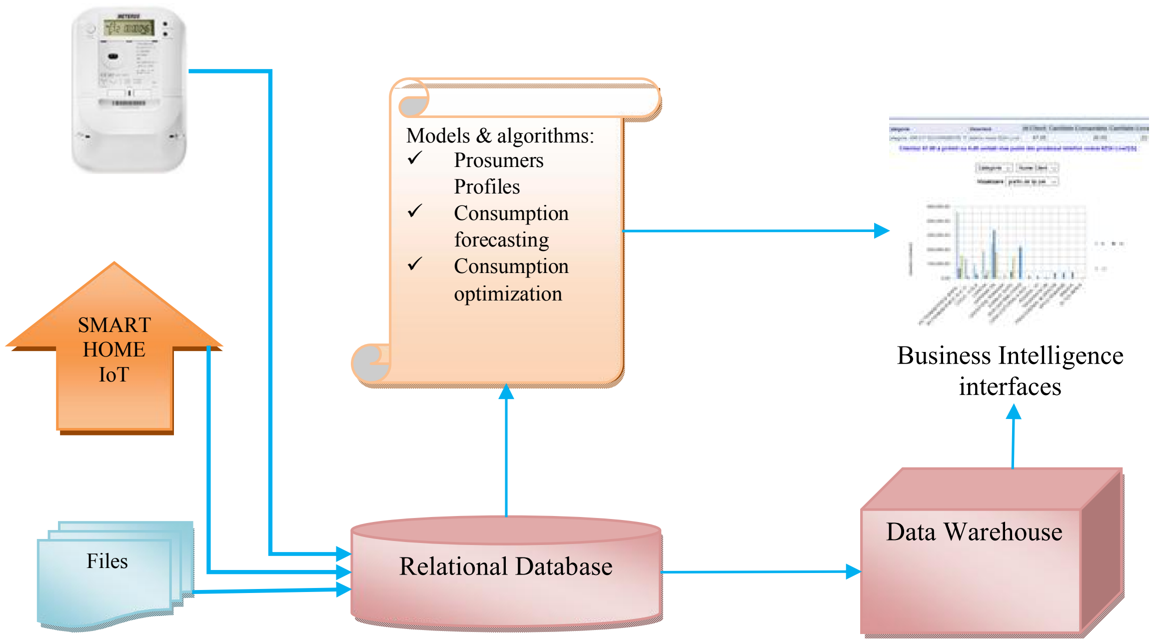

Fig. 1. The prototype's architecture

For the components' implementation we'll use MySQL database and Java platform, these technologies are described in the next paragraphs.

6 Software technologies

In order to implement the previously proposed architecture, current technologies need to be used. MySQL, Java, Business Intelligence (BI), Cloud environment are just some of the technological components that are going to be used for the software prototype that satisfies the electricity prosumers. All these technologies have a stable trend of being used and bringing new functionalities to a system that is standardized and well documented.

MySQL Database Management System (DBMS) is a multi-thread, multi-user, relational database management system. It runs like a server offering to multiple users' access to several databases. Most common programming languages (including Java) can access MySQL databases using libraries through API interfaces. Also, an ODBC (Open Database Connectivity) interface, called MyODBC, allows programming languages to communicate with MySQL databases.
MySQL works on a widely range of platforms like Windows, Linux, MAC OS, etc. The latest stable release (5.7.16) dates from 12 October 2016. MySQL capabilities include stored procedures, triggers, cursors, views, nested requests.

MySQL can be used on Cloud Computing platforms either by a virtual machine image or by a service (platform as a service).

Java platform includes the necessary software tool for developing a complete desktop or web application, like java applets that can be integrated in HTML scripts. Java programming language runs on a virtual machine (JVM), but there are also compilers for Ruby, Python, Ada, JavaScript.

Java is widely used for many years because of its maturity, multiple API interfaces and many open source libraries. Version 5.0 chanced a bit its simple philosophy by including *foreach* constructor, *autoboxing* property (passing from primitive types to the corresponding class without any necessary source code), methods with variable number of parameters, generic types, etc.

Java platform exists in four formats depending on the target application to be developed. Java Card is for small applets that run on small memory devices. Java Micro Edition (ME) is used for mobile applications, Standard Edition (SE) works for servers and desktops, while Enterprise Edition (EE) is for complex client-server enterprise applications. The current version is Java 8.

BI solutions include digital dashboards in different formats that apply data analysis and data mining techniques. These operations start from simple summarizing and sorting to clustering and pattern recognition. Also, Online Analytical Processing (OLAP) is the main tool used for processing data, through its drill-down, roll-up, slicing and dicing operations. The formats of displaying the results can be charts, tables, maps, graphs and interactive elements.

Most BI applications are Web-based because of the great opening they offer, but the best of them are Cloud-based. Cloud BI are hosted on web virtual machines as services. According to [24] Cloud BI solutions eliminate the software maintenance and the backup routines and also, by using web frameworks the costs of developing the applications are significantly reduced. The main problem that appears for Cloud applications in general, (and for BI in particular, because of its huge amount of private data exposed) is the security of data.

Cloud computing is a type of computing architecture that focuses on sharing the resources, data and applications between users. The sharing is done on–demand depending on the necessary of functionalities, storage capabilities or hardware support.

Cloud environment has three layers that need to be virtualized as services: infrastructure (the hardware components), platform (the software tools), software (functionalities brought by specific applications).

In **Fig. 2**, we propose a cloud frame for the BI application that is going to meet the energy prosumers requests. The SaaS is represented by on-demand functionalities like energy consumptions/producing predictions, consuming trends, spatial representation of energy sources, etc. The PaaS is the Java platform and the IaaS refers to sharing memory resources.

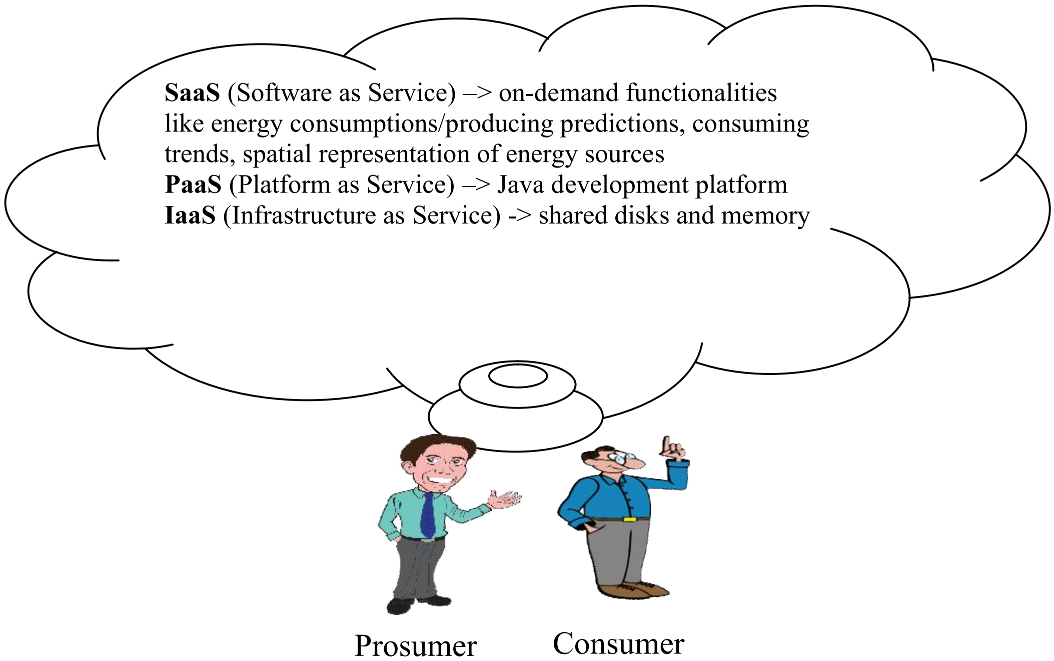

Fig. 2. Cloud BI architecture

Developing the application that is flexible, open, uses modern and stable technologies needs to take into account the Cloud architecture in which Java fits very well as a Platform service and BI offers on-demand app services. For data storing, MySQL turns out to be a reliable relational DBMS with plenty of capabilities and satisfying querying performances.

6. Conclusions and future works

In this paper we have presented related works and described the new technology – smart metering system that belongs to our partner Repower Furnizare Romania SRL. Then we have described the main research objectives related to our project PN-III-P2-2.1-BG-2016-0286 "Informatics solutions for electricity consumption analysis and optimization in smart grids"

Afterwards we have identified the main informatics solution requirements and describe the main software technology (MySQL, Java, BI, Cloud computing) that we will use in our research. Finally, we proposed a prototype architecture based on the three levels: data, models, interfaces.

In the near future, our project team will develop the data management model by integrating data from SMS and from IoT appliances into a database, centralized at the electricity supplier level for performant and real-time dynamic analysis.

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