Smart Energy Manager for Energy Efficient Buildings

Lazar Berbakov
Institute Mihajlo Pupin
Belgrade, Serbia
lazar.berbakov@pupin.rs

Marko Batić
Institute Mihajlo Pupin
Belgrade, Serbia
marko.batic@pupin.rs

Nikola Tomašević
Institute Mihajlo Pupin
Belgrade, Serbia
nikola.tomasevic@pupin.rs

***Abstract*—In recent years, advances in wireless communications, microelectronics and sensing technology have allowed a production of computationally capable low-cost miniature devices that can be used in different innovative solutions. Due to constant increase of energy consumption, and since residential sector has been identified as one the most energy demanding, there exists a strong interest in exploitation of connected smart devices with the aim of improving energy efficiency, user comfort and the overall quality of life. The Smart Energy Manager based on an IoT platform which will be presented in this paper aims to reach the aforementioned goals with the combination of monitoring and control devices with the advanced energy services capable of analyzing the collected data and providing control actions and suggestions aimed at the end users via intuitive end-user applications.**

Keywords—Internet of Things, Smart Buildings, Platform Architecture

I. Introduction

Recent advances in wireless communications, microelectronics fabrication, and sensor miniaturization have enabled a mass production of low-cost yet computationally capable miniature devices which can be used in different innovative solutions. Steady acceleration of technological advancements and expected growth of human population will undoubtedly require an increase of energy production which will in turn require significant investments in the energy production and distribution infrastructure. Another option would be to shift the behavior of the general community towards more energy efficient and less wasteful practices. Since residential sector has been identified as one the most energy demanding, there exists a strong interest in exploitation of wirelessly connected smart devices with the goal of improving energy efficiency, user comfort and the overall quality of life.

This opportunity was partially addressed during FP7 project Energy Warden [1] where the focus has been put on the optimization of renewable energy technology (RET) deployment in the building domain. On the other hand, during the EPIC-HUB project [2], the aim was to develop a new methodology, an extended architecture and services able to provide improved Energy Performances to Neighborhoods. This goal was achieved by a combination of pre-existing and new ICT systems with Energy-Hub-based Energy Optimization capabilities.

An extensive amount of research has been focused on smart home and building automation interoperability, as elaborated by Jarvinen and Vuorimaa [3] and reported by Jiang et al. [4]. There are many possible typologies of architectures to improve interoperability with smart home devices as investigated by Capitanelli et al. [5].

For instance, many studies have been concentrated on connecting heterogeneous devices and subsystems together, and providing a unified interface on top (such as in studies performed by Perumal et al. [6], Wang et al. [7], Tokunaga et al. [8], and Miori et al. [9]). One of the protocols for the unified high-level Web services interface is open Building Information eXchange (oBIX) (Considine [10]) proposed by the Organization for the Advancement of Structured Information Standards (OASIS). This data format is based on XML and defines, similarly to any common programming language, a small set of primitive data types for describing the data. Coyle et al. suggested a sensor fusion-based middleware for smart homes, called ConStruct (Coyle et al. [11]).

In order to ensure that all the devices communicate using the common messaging format a canonical data model (CDM) shall be defined. In the literature, there exist a number of standards aimed to ensure interoperability in energy management domain. The Energy interoperation presents an information and communication model aimed to enable collaborative and transactive use of energy service definitions consistent with the OASIS SOA (Service Oriented Architecture) reference model [12]. The Common Information Model (CIM), a standard developed by the electric power industry that has been adopted by the International Electrotechnical Commission (IEC), aims to enable application software to exchange information about an electrical network [13]. The standard that defines the core packages of the CIM is IEC 61970-301, with a focus on the needs of electricity transmission, where related applications include energy management system, SCADA, planning and optimization.

The platform which will be developed within the ongoing InBetween project aims to combine smart monitoring and control devices with the advanced energy services capable of analyzing the collected data and providing control actions and suggestions towards the end users via intuitive mobile and web applications. InBetween aims to help users to identify their energy wastes, teach them how to conserve energy, motivate them to act and instruct them to actually carry out energy efficiency practices. Besides, it will provide cost-efficient solution that brings added value without significantly disrupting user's daily activities and comfort.

The aim of this document is to present an Internet of Things (IoT) platform whose main goal is to support end-user in achieving energy efficient living. First, a platform architecture focused on IoT cloud functionalities is described. Next, the identification of platform use cases will be presented. Finally, mobile app and the detailed overview of advanced energy services is provided.

II. IoT Cloud Platform

A. *Platform architecture*

The IoT platform which will be presented in this paper represents a highly flexible, cloud-based, IoT platform which will integrate energy monitoring and automation devices with environment sensing and innovative advanced energy services, as shown in Figure 1.

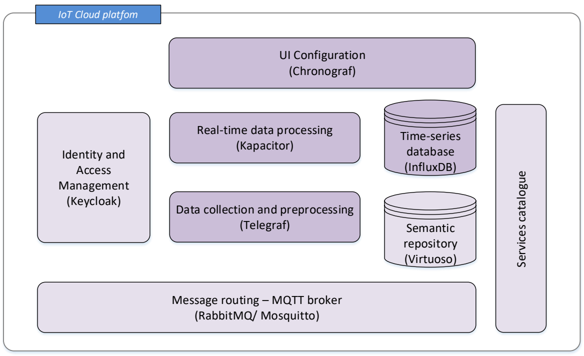

Figure 1. InBetween IoT cloud platform

In Figure 1, we highlight the InfluxData TICK Stack, composed of Telegraf, InfluxDB, Chronograf, and Kapacitor. These components can be configured and some tests can be performed in order to verify that sensor successfully acquire data by their visualisation via a test GUI (Chronograf). Lightweight message exchange broker (e.g. Mosquitto MQTT broker) is used to collect measurements from field level sensors as well as to send control actions to the actuators. InfluxDB is used to store the collected data, whereas Kapacitor can be used to process the data in real-time. Next, Telegraf is used as an interface between Message broker and InfluxDB, with the aim to parse the received messages and store the data in the database. Finally, identity and access control is provided by Keycloak while Virtuoso serves as a semantic repository which is used to store the data related to the deployed devices.

B. *Platform use cases*

Although InBetween aims to build a comprehensive platform, its approach does not entail development of general solution that fits all. In particular, the proposed platform will try to induce energy related behaviour changes through personalized recommendations and decision support. In other words, the platform will provide relevant cost and energy saving measures which are relevant to particular user, who is then able to follow them without compromising personal daily routine and convenience. The aim of this section is to identify different use cases for the platform. In particular, we seek different aspects in which the platform may contribute to reaching improved energy and cost efficiency, and allow end-users to:

1. Reduction of energy wastes – by detecting wasteful practices through cross-correlation of information about operating heating/cooling systems and lighting devices with ambient and occupancy sensing collected by deployed field devices..

2. Optimal energy infrastructure operation – by optimally satisfying requested energy demand based on information about available energy assets and dynamic energy pricing context, prediction of local generation etc.

3. Evaluate performance and benchmark – by periodically assessing user's energy performance and raising awareness through benchmarking with similar/neighbouring end users.

The three core features of InBetween platform will be based on availability of devices dedicated to energy demand monitoring and home automation (such as electricity/gas meters, calorimeters, smart plugs and relays etc.), ambient and environment sensing (luminance, temperature, humidity, CO/CO2, occupancy etc.) and InBetween's advanced energy services.

The later will comprise of the following services:

- Consumption analytics service (CAS), dedicated to consumption disaggregation, i.e. estimation of appliance-level electricity consumption from a single metering point;
- Consumption forecast service (CFS), offering prediction of near future energy related behaviour;
- User profiling service (UPS), focusing on profiling and categorization of end-user and their consumption;
- Energy dispatch optimization service (EDOS), delivering optimal energy dispatch strategy for existing energy assets while satisfying various economic, environmental, societal and technological criteria;
- Energy performance evaluation and benchmarking service (EPEBS), enabling end user's energy performance and its benchmarking against 'similar' end users.

Although each of these services represent part of same value chain, they will be implemented and deployed independently operating as a black box from the platform's perspective requiring specific inputs and offering corresponding outputs. The particular choice and their integration into a unified workflow will depend on the requirements of each use-case which will also define which services are required and what will be their corresponding sequence of operation. When it comes to communicating devised energy conservation measures and personalized recommendations to the end-users, both Mobile and Web clients will be made available with their intuitive and user-friendly GUIs.

III. Visualisation and Advanced Energy Services and Layer

In this section, we present the core value provided by the InBetween platform that comprise advanced energy services and the corresponding visualisation layer.

A. *Smart Energy Manager mobile application*

SEM app (shown in Figure 2) is based on Android OS and serves as the main platform interface towards the end user, allowing it to observe measured data, obtain suggestions and even perform some of the control actions automatically (e.g. switching the appliances remotely). After the user performs login by using username and password combination, it is presented with the main app dashboard (see Figure 2 below). In the upper part of the screen, the user is given information about average temperature (across all temperature sensors deployed in household) and the current outdoor weather conditions (obtained by external weather service weatherbit.io). Next, the user is shown the information about current aggregated power consumption (obtained from the smart meter), and the total energy consumption for the current month. Finally, weather forecast for the next three days is shown. Although SEM is primarily aimed at energy management, we decided to include additional functionality in the form of weather forecast, in order to engage users early during the project, when the so called baselining is performed. The aim of baselining is to create a basis against which to compare the benefits of the InBetween platform later during the project.

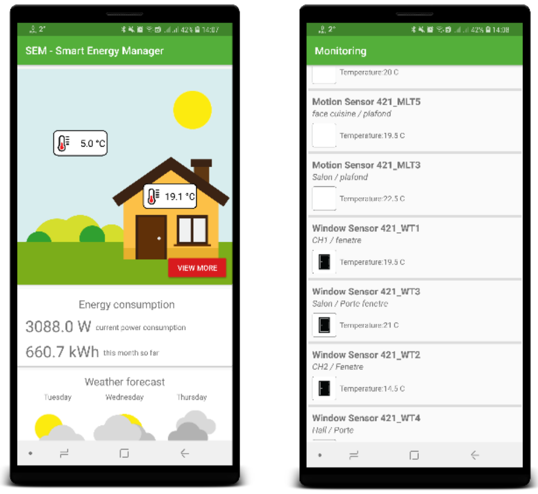

Figure 2 SEM Mobile application user interface

The advanced energy services consist of number of interrelated software modules that work on top of data that are stored in cloud based layer, extracting valuable information and providing user recommendations and control actions aiming to enable reduction in energy consumption and associated costs, increase of end user energy efficiency, flattening peaks in consumption profile, balance appliance utilization with green energy availability etc.

B. *Consumption analytics service*

One of the purposes of Consumption analytics service (CAS) is to enable disaggregation of loads monitored through a single metering point and help finding the correlation between cumulative energy consumption and individual consumption yielded by a particular device/appliance. In case of a household, this single metering point may refer to a location of a smart meter (or conventional one) measuring the entire household consumption or, in case of a non-residential building, it may refer to only a part of a building (e.g. building floor) for which aggregated monitoring of consumption is available. In other words, the overall ambition is to use existing analytics methods and tools to reach information about individual device/appliance consumption without deployment of additional monitoring.

The CAS will therefore be leveraged on the well-known process of Non-Intrusive Load Monitoring (NILM) which is based on constant monitoring and analysis of changes in the voltage and current levels of power consumed at a designated, aggregated, level (e.g. point where smart meter is located) and aims to deduce what devices/appliances are used in a specific moment in time as well as to estimate their individual energy consumption. For this purpose, a set of automated/machine learning algorithms and techniques (e.g. support vector machine, ANN) will be employed. Moreover, CAS will follow a flexible development approach enabling its application in both residential and non-residential use cases which entails its flexibility in terms of devices/appliance to be supported, technical properties of existing energy monitoring infrastructure (sampling frequency, spatial resolution etc.), availability of so called labelled data which enable supervised learning, different metrics used for evaluation of performance etc.

In addition, CAS will provide the detection of potentially wasteful user behaviours based on heuristic algorithms that will deal with raw collected data as well as the processed ones (e.g. NILM). These algorithms will be able to detect situations where e.g. a window is open while the heater or air-conditioner are working, and to send a suggestion to the user, so that the energy and cost wastes are prevented in a timely manner

C. *Consumption forecast service*

Consumption forecast service (CFS) aims to provide the detailed analysis of consumption data and the prediction of the energy demand. The availability of a Consumption Forecast, at operation time, represents a key input to the Energy Dispatch Optimization service. Besides, it also helps operators to determine which configuration of machinery and associated set points are necessary to meet the desired comfort levels, at the lowest operational cost. By using CFS, Consumption data gathered either from CAS or measured directly on the particular appliance will be further processed by algorithms based on knowledge discovery in databases (KDD) and on predictive analytics (PA). Besides, additional semantic information such as building type and constructional data, as well as previous consumption patterns, weather, user behaviour will be exploited with the aim of improving the accuracy of the prediction. Finally, as a result, the Consumption forecast service will provide the energy demand curve for specific load (household, building, etc.) during the given time frame.

D. *User profiling service*

User profiling service (UPS) aims to identify user profiles based on the monitored energy consumption, building physical properties, occupancy, environmental data, weather conditions, etc. It employs data driven models, trained using the supplied monitoring data, and building/apartment/user metadata, to create user profiles, that can further help in the process of consumption forecasting and anomaly detection. The profiling service can be configured to automatically use all, some, or different combinations of classifiers for model generation depending on their availability. The identified profiles will be further used as an input to performance benchmarking and micro-optimization services.

E. *Energy dispatch optimization service*

Energy dispatch optimization service (EDOS) aims to provide optimal energy dispatch strategy in a complex energy environment involving different conventional and renewable energy sources, various electrical and thermal energy storages and dynamic energy pricing schemes under user-defined objectives. EDOS is configured for the specific deployment instance considering different types of energies that are available, energy conversion options, and other relevant parameters. It employs energy demand predictions data provided by Consumption forecast service in order to calculate the optimal energy consumption patterns that can be further translated into control actions and recommendations for users on how to optimally use both energy resources and corresponding assets. Besides, the actual energy consumption provided by the InBetween monitoring platform along with information on on-site energy production and applicable pricing scheme are employed by Energy dispatch optimization service in order to provide optimal energy supply mix and scheduling of available energy conversion assets. The output of this service will be directly communicated to the end user via dedicated user interfaces such as in-home display, smartphone, and desktop computer.

F. Energy performance evaluation and benchmarking service

Energy performance evaluation and benchmarking service (EPEBS) represents one of the very core services provided by the InBetween platform which aims to contribute to a greater end user engagement related to energy saving actions and focuses on raising the awareness of people about how much energy they consume compared to similar consumers. To do so, EPEBS will first deliver an estimation of overall end user energy performance calculated for each individual household or commercial/public building and, secondly, will use this performance to provide self-comparison and benchmarking against different similar users, thus generating a positive social pressure capable of inducing behavioural changes in this regard.

Having selected an approach which compares end user's 'energy performance' instead of actual 'energy consumption' allows for having a fair benchmarking which sets realistic and achievable goals for end user rather than unrealistic ones that discourage further engagement and reduce the effectiveness of the technology over time. EPEBS will employ data driven algorithms that take energy consumption, provided by the InBetween monitoring components, as main input together with a range of contextual metadata, such as climate conditions, number of occupants, building materials etc. Based on this data, the service will perform normalization of actual energy consumption with corresponding user specific data in order to calculate end user energy performance.

IV. Conclusion

In this document, we presented the InBetween IoT platform aimed at improving energy efficiency of smart buildings. The platform itself is based on open source software which is used for integration of the devices deployed in the field with the advanced energy services. Finally, the advanced energy services, which are combined depending on the use case, are used to analyze the user energy consumption habits and propose the recommendations delivered via mobile application to steer users towards more energy-efficient lifestyle.

Acknowledgment

This work was partly financed by the European Union (H2020 InBetween project, Pr. No: 768776), H2020 LAMBDA project, Pr. No: 809965) and by the Ministry of Science and Technological Development of Republic of Serbia (Pr. No: TR-32010).

References

[1] FP7 project EnergyWarden

[2] FP7 project EPIC-HUB

[3] Jarvinen H., and Vuorimaa P., "Semantic Interoperability for Web Services based Smart Home Systems," In Proceedings of the International Conference on Agents and Artificial Intelligence (ICAART-2015), pages141-148.

[4] Jiang, L., Liu, D.-Y., Yang, B., et al. (2004). Smart home research. In Proceedings of the Third Conference on Machine Learning and Cybernetics, pages 659–664.

[5] Capitaneli A., Papetti A., Peruzzini M., Germani M., "A smart home information management model for device interoperability simulation," at 24th CIRP Design Conference, Milan, Italy, 14–16 April, 2014, CIRP21 (2014) 64–69.

[6] Perumal, T., Ramli, A.R., Leong, C.Y., Samsudin, K., and Mansor, S. (2010). Middleware for heterogeneous subsystems interoperability in intelligent buildings. Automation in Construction, 19(2):160–168.

[7] Wang, S., Xu, Z., Cao, J., and Zhang, J. (2007). A middleware for web service-enabled integration and interoperation of intelligent building systems. Automation in Construction, 16(1):112–121.CAADFutures, 2005.

[8] Tokunaga, E., Ishikawa, H., Kurahashi, M., Morimoto, Y., and Nakajima, T. (2002). A framework for connecting home computing middleware. In ICDCSW, pages 765–770, Washington, DC, USA. IEEE ComputerSociety.

[9] Miori, V., Tarrini, L., Manca, M., and Tolomei, G. (2006). An open standard solution for domotic interoperability. 52(1):97–103.

[10] Considine, T. (2010). Open Building Information Exchange (oBIX) version1.1.OASIS Working Draft 06, June 2010.

[11] Coyle, L., Neely, S., Stevenson, G., Sullivan, M., Dobson, S., and Nixon, P. (2007). Sensor fusion-based middleware for smart homes. International Journal of Assistive Robotics and Mechatronics, 8(2):53–60.

[12] OASIS Energy Interoperation TC: https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=energyinterop

[13] Energy management system application program interface (EMS-API): https://webstore.iec.ch/publication/31356