IoT based energy efficiency platform architecture design considerations

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***Abstract* – The paper discusses possible system architectures and corresponding deployment models for an IoT-based platform for increasing energy efficiency of end-users and facilitating change in their behaviour in this regard. The main objective is to provide for a flexible and modular architecture able to integrate IoT based monitoring and actuating devices with advance energy services. A brief overview of the most prominent middleware-based architectures capable of providing integration of heterogeneous hardware and software components is followed by the proposed system architecture and deployment model. Finally, a proposal for implementation of architecture building blocks is given through state-of-the art open source solutions.**

I. INTRODUCTION

A. Motivation

The main objective of this paper is to elaborate on the possible architecture and system integration approach for the IoT-based energy efficiency platform, initially introduced in [1]. As previously described, the proposed platform leverages on the energy related data collected from the existing home automation systems and/or monitoring platforms to underpin the development of advance energy services aiming to facilitate transition towards energy efficient behaviours through direct end-user engagement. In particular, the advance energy services will leverage upon the monitored energy consumption to estimate individual energy efficiency performance, detect potential performance deviation and consequently deliver customized energy conservation measures. Moreover, one of the services will also focus on providing a benchmarking tool allowing the end-users the compare their consumptions with "similar" consumers but also with themselves. These services will be developed and operated independently, delivering innovative features such as consumption analytics, profiling and prediction, demand optimization and, finally, the performance evaluation and benchmarking. Given the selected service oriented approach and modular development, the proposed solution will feature high service orchestration flexibility and allow for high replicability and reusability of developed services.

The overall system functional view represented logical clustering of key desired system functions, their mutual interrelations and corresponding interfaces. However, to be able to develop and deploy the described system in terms of software artefacts and required hardware components, it is necessary to select the most suitable system architecture and corresponding deployment model. Moreover, once the deployment model is selected, it is also necessary to investigate the feasibility of the proposed architecture by identifying interoperability challenges and existing hardware and software components having the capacity to tackle them.

B. Identification of platform use-cases

In general, the proposed solution will represent a highly flexible, cloud-based, IoT platform which will integrate energy monitoring and automation devices with environment sensing and innovative energy services. Although it is aimed to develop a comprehensive platform the undertaken approach will not follow the principle 'one size solution that fits all'. On the contrary, the proposed platform will try to induce energy related behaviour changes through tailored recommendations, decision support and guided action. In other words, the platform will provide relevant energy and cost saving measures that are relevant to a specific end user, who is then able to act upon them without compromising personal comfort and convenience. Moreover, the platform will engage end users through specific incentives according to their preferences and limitations [5][6][7].

The aim of this section is to determine different use cases for the proposed ICT platform, i.e. different aspects in which the platform may contribute to reaching improved energy and cost efficiency. Seeking for different ways to raise end-user awareness in energy and environmental related aspects and aiming to induce a behavioural change in this regard, the platform will follow a comprehensive approach which shall allow end-users the following platform use cases:

Reduction of energy wastes (Use Case #1): by detecting wasteful practices through cross-correlation of information about operating heating/cooling systems and lighting devices with ambient and occupancy sensing, end user will be presented with appropriate energy conservation measure.

Optimal energy infrastructure operation (Use Case #2): by optimally satisfying requested energy demand based on information about available energy assets and dynamic energy pricing context, forecast of local generation etc.

Evaluate performance and benchmark (Use Case #3): by periodically assessing energy performance and raising awareness through benchmarking with similar/neighbouring end users.

The three core use cases for proposed ICT platform will be leveraged upon availability of devices dedicated to energy monitoring and home automation (such as electricity/gas meters, calorimeters, smart plugs and relays etc.), ambient and environment sensing (temperature, luminance, humidity, CO/CO2, occupancy etc.) and 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;
- User profiling service (UPS), focusing on profiling and categorization of end-user and their consumption;
- Consumption forecast service (CFS), offering prediction of near future energy related behaviour;
- 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 developed and deployed independently operating as a black box from the platform's perspective requiring specific inputs and offering corresponding outputs, which are detailed in one of the following chapters. 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 or corresponding performance deviation notifications both Mobile and Web clients will be made available with their intuitive and user-friendly GUIs. Following are brief descriptions of the three use cases, especially highlighting the featured energy services.

The Use Case #1 platform will primarily look for the so called 'quick wins' related to overall energy efficiency and thus seek for the wasteful energy practices which can avoided without compromising end user comfort and operational capacity. Hence, it will combine energy consumption information from major consumers, such as heating and cooling system and lighting, with ambient and occupancy sensing to deliver custom, end-user tailored, energy conservation measures (ECMs). The typical energy wastes, such as open windows in HVAC conditioned area or working lights during the daylight, have enormous, untapped, potential for avoiding energy wastes and thus increasing the end user efficiency. Once energy wastes are minimized, within the Use Case #2, the platform will assist end users in reaching optimal energy infrastructure operation strategy for satisfaction of the remaining energy demand. Proposed operation strategy will leverage user-centric energy consumption modelling and consumption prediction combined with pricing/load/stability information received from ESCOs. In particular, it will consider available energy carriers and sources such as power grid, district heating, renewables etc., energy conversion assets such as electric boilers, heat pumps, furnace etc. and dynamic energy pricing context for each energy carrier. Moreover, this use case will also capitalize on increasing Demand Response and Demand Side Management programmes through integrated optimisation of energy supply and demand which takes additional inputs related to load characterisation (e.g. classification into critical, reschedulable and curtailable loads), required comfort levels, etc. In other words, the platform will extend information supplied through energy conservation measures by performing comprehensive energy infrastructure operation optimization to detect optimal energy management strategy of available energy assets. Although optimal energy management strategy is often associated with minimization of operation costs, the optimisation service will bring the flexibility of multi-criteria decision making process so as to simultaneously evaluate range of economic, environmental, technical and societal criteria. The Use Case #3 will offer end users a more general feedback related to their energy related performance aiming to create a positive social pressure and raise awareness [8][9]. Namely, by aiming to understand barriers for action, and target those specifically, the proposed solution will adopt an approach of providing 'fair' comparison (fair, as perceived and defined by end user) which will enable unique social nudges (i.e. positive reinforcement) towards the desired behaviour change. The platform will bring the ability to benchmark and compete through evaluation of end user energy social practice and performance rather than just consumption. The performance evaluation considers normalization of consumption against a range of 'objective parameters' such as building size, construction material properties, number of occupants, climate conditions etc. Moreover, current adoption barriers, faced by the similar ICT platforms, will be tackled by using energy services approach (rather than energy consumption) and by incorporating insights and methodologies for user engagement from the 'Practice theory' and the 'middle out framework'.

Necessary information and data flow behind the aforementioned use cases is depicted in Figure 2. In particular, the figure summarizes employed advanced energy services and necessary steps to fulfil the workflow. All three use-cases share the same part of workflow dealing with the energy/ambient monitoring, corresponding data analytics/processing and visualisation. Namely, this part of the workflow is responsible for 1) acquiring and storing raw monitoring data in the Data repository and 2) data enrichment based on load disaggregation performed by the Consumption analytics service (which implements Non-intrusive load monitoring techniques, *NILM* [10]) and User profiling service. It should be noted that load disaggregation techniques are employed in cases when existing energy monitoring does not provide for sufficiently detailed consumption information. Also, a common part of the workflow is also Visualization which serves for presentation of monitored energy and ambient data but also provides interface for presentation of intermediate outputs from each service and, the most importantly, is used to communicate derived recommendations/actions/awareness information. The Use Case #1 requires an additional proprietary component, called ECM inference engine, will be employed to detect wasteful practices from ambient monitoring data and corresponding outputs from analytics/profiling services, using heuristic based methods. The Use Case #2 employs proprietary components/services starting with the Consumption forecast service which takes archived data from consumption monitoring and various contextual information to deliver short-term predictions regarding energy consumption [11]. Output from this service is then fed into Energy dispatch optimisation service which is another proprietary component of this use

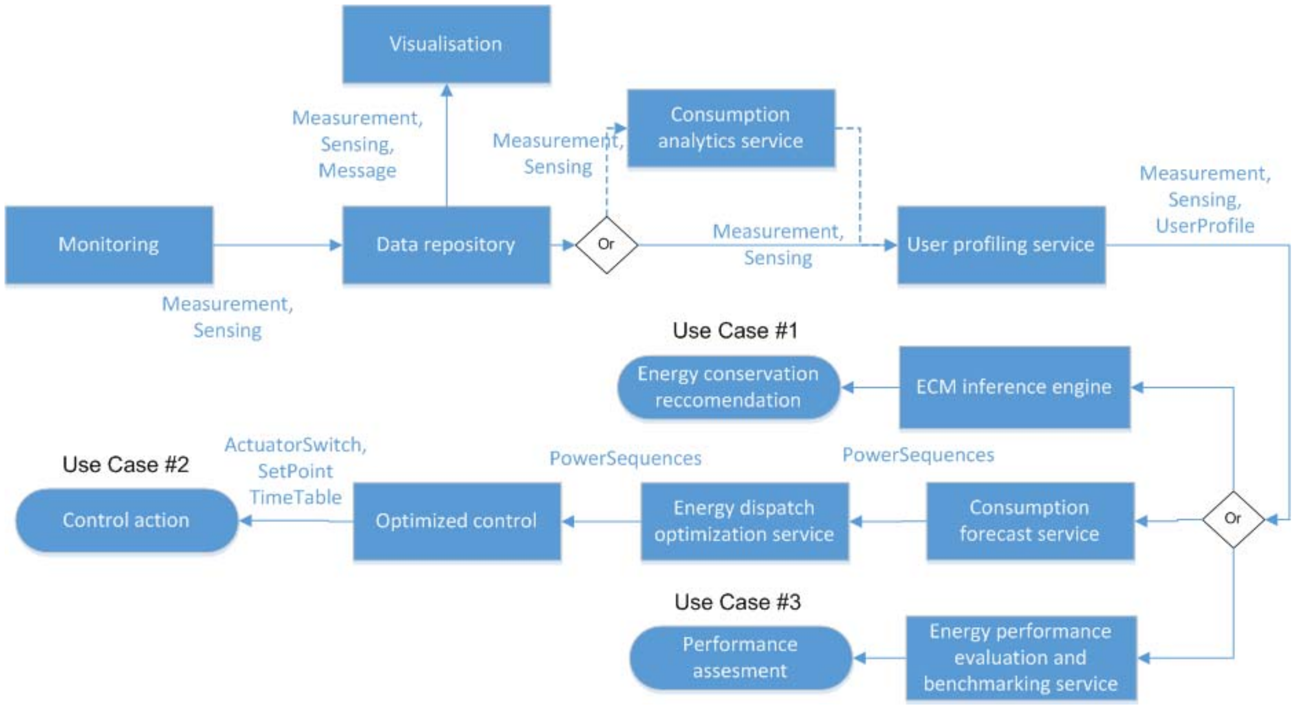

Figure 2: Data flow diagram for proposed platform use cases

case. The Energy dispatch optimization service will deliver optimal energy supply and consumption profiles [15][16][17], for each energy carrier and load types respectively, to the component referred to as Optimised control which main responsibility is to translate outputs from the optimisation service into actual control actions applicable by end user through existing energy assets. In other words, this component will ensure that an optimal operation strategy is communicated to the end user in the form of manual, semi-automatic or automatic controls such as actuator switch, set-point, time table etc. The Use Case #3 requires, however, additional proprietary Energy performance evaluation and benchmarking service. This service takes energy and ambient monitoring data, enriched with corresponding analytics/profiling services to evaluate end user energy performance through normalization of energy consumption against a range of contextual parameters, such as climate conditions, building construction material, number of inhabitants etc. [12][13][14]. Such normalization is employed to ensure that an objective performance indicator is calculated which sets the ground for comparison and benchmarking with other end users.

C. *Research questions and SoA*

The focus of the conducted research is on selection of the appropriate system architecture and corresponding deployment model given the requirement to integrate different hardware and software components devoted to energy monitoring and control at building/household level. The problem has been known and investigated for several years and the existing literature has emphasized that the complexity of this integration is severely dependent on the number of different devices employed, existing on-site energy generation and storage etc. In principle, the most widely acknowledge solutions referred to the use of data-unifying layer for tackling this problem. This layer focuses on abstraction of the complexity of lower components of facility and aims to solve the interoperability challenges through unification and conversion of data coming from lower software levels, thus overcoming any format-related issues for pluggable application layers. The following is an overview of different middleware architecture proposals in the context of energy management.

The AIM project [2] present a framework architecture for modelling, visualizing and managing energy consumption of home appliances. The projects proposes development of a gateway which consist of the three separate modules: i) a module providing machine-to-machine interfaces through a common API for implementation of gateway-related services, ii) an identify management module for user authentication and authorization, and iii) a module for service integration and orchestration offering also creation of new, composite, services upon such integration. The HYDRA project [3] brought a generic middleware platform for heterogeneous devices which facilitated communications between the devices and provided an architectural infrastructure for network abstraction, event management and services communications. It was not built primarily for energy efficiency purposes, however it provided infrastructure for construction energy-aware solutions. The EPIC-Hub project [4] developed a new methodology, an extended architecture and services able to provide improved energy performances both on building and neighbourhood level. It leverages upon energy gateways to integrate various data sources in the middleware architecture and offer implementation of advance energy demand and supply optimization services.

When it comes to the possible deployment models for the system architecture, they have a strong influence on underlying hardware requirements, location of data sources, where data is generated, transported and consumed across the value chain and they also affect the type of business models which can be supported. Moreover, they also affect further design of actual software components of the system.

II. METHODOLOGY

The presented research examines the deployment models from the perspective of the two key stakeholders: the energy utility (both electricity and gas) and the energy end-user, i.e. the customer. For this stakeholder constellation, the three types of deployment models are considered, as elaborated in the following.

A cloud-based deployment model: which assumes that system components are deployed in a private cloud of an energy provider or energy service company (ESCO). Furthermore, it builds on a fact that both energy monitoring and ICT equipment is under full control of energy and/or service provider and that information about end-users is centrally available. The monitoring equipment located at the end-user is relatively lightweight, e.g. a single smart meter for entire household and does not penetrate into premises of the end-user.

An extended edge deployment model: system components are distributed between a private cloud governed by the energy/service provider and edge systems deployed at the end-user premises (e.g. energy gateways) and/or distribution network. This deployment model assumes that some of the end-user oriented services can be provided by the edge systems (e.g. energy gateways), thus forwarding only the necessary information to the central system while leaving some simple calculations and decision making (with corresponding alarms and notifications) for the edge systems and components. Energy monitoring, such as smart meters/occupancy/ambience sensing, as well as actuation equipment such as smart plugs/boilers/EVs, can penetrate the end-user premises and offer a richer information and control environment to be locally exploited.

A hybrid deployment model: this model assumes that not all end-user will have edge system, and corresponding components, deployed at their premises. As a result, some end-users, with limited hardware deployment will only use the cloud-based part of the solution while the others, offering more advance monitoring and control capabilities, are able to use the system functionalities to the full extent. Such deployment model allows for development of flexible business model and larger market outreach.

III. SOLUTION

The most appropriate deployment model to be finally considered is a hybrid model which can strive the balance between the advantages and disadvantages that each of the deployment model offers. Inspired by aforementioned state of the art of previously employed system architectures, the proposed platform architecture is depicted in Figure 2. The figure shows key layers and the main functional dependencies among sub-systems which can, from an ICT perspective, be classified into the three layers, as follows.

The Gateway layer comprises different sensors, actuators and metering equipment that are deployed at the buildings and inside the households and connected via gateways to the rest of the InBetween platform. The aim of this layer is to ensure the collection of different measurements (power consumption, temperature, etc.) that will be stored in InBetween cloud platform, further processed by advanced energy services and presented to the end users via web and mobile applications. Besides, the InBetween platform will be able to perform control actions

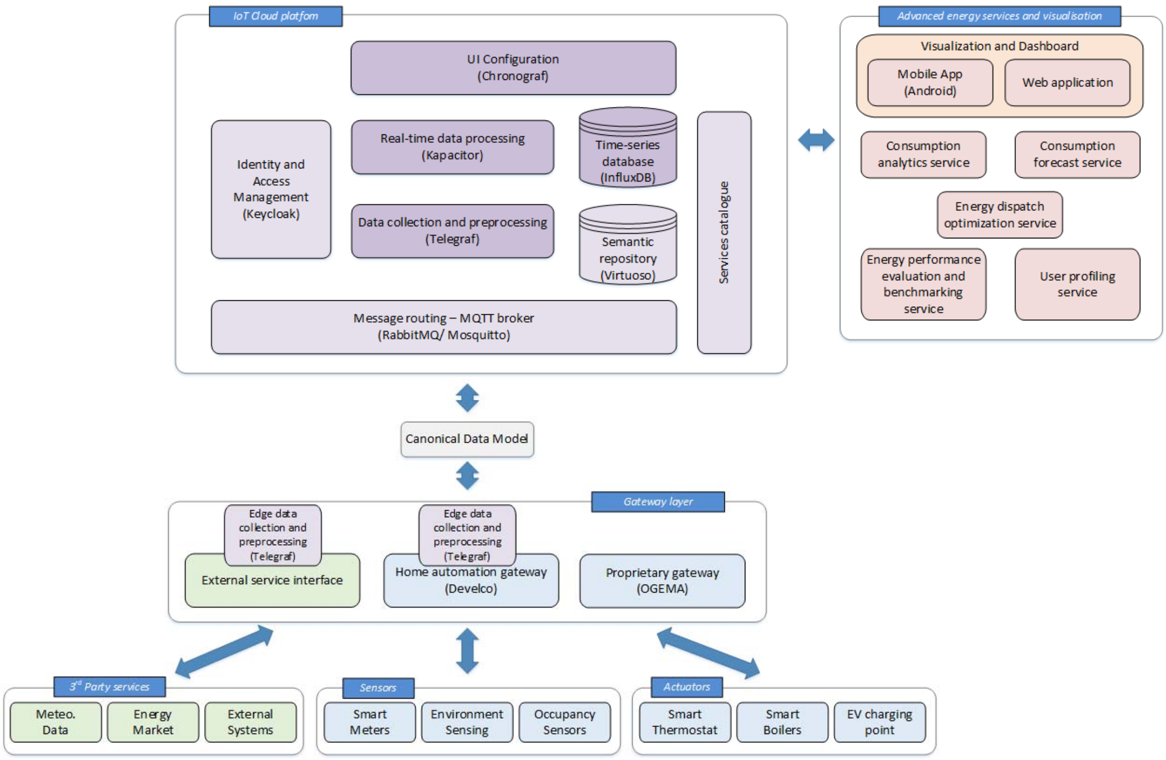

Figure 2: Proposed architecture

(turn on/off the boiler, set the temperature on HVAC, etc.) following decisions made by advanced energy services. Finally, this layer also includes a number of interfaces towards external services that will be used to get data related to energy pricing, weather, etc.

IoT Cloud platform layer is the main data collecting and processing point of the InBetween platform. Its main functionalities include lightweight message exchange (MQTT or AMQP message broker), data storage optimized for time series data (InfluxDB) and identity and access component (Keycloak) that will provide centralized authentication and authorization management. In addition the semantic data related to the deployed devices will be stored inside a semantic repository (Virtuoso), whereas real-time data processing will be performed by Kapacitor component.

Advanced energy services and visualisation layer comprises a number of services used for energy consumption analytics and forecast, energy optimization, user profiling and benchmarking, as well as a web and a mobile application that provide visual user interface for energy managers and building occupants. This layer employs information collected by the monitoring and control layer that have been stored in the IoT Cloud platform. The collected data are processed by means of advanced energy services that result in a number of control actions performed by the deployed actuators (smart plugs, relays, etc.) and recommendations for users aimed to change their behaviour towards more energy efficient lifestyle.

When it comes to the component implementation, the InfluxData open source framework, offering contemporary time-series platform and handling metrics and events was selected as the best candidate for the backbone of the proposed system. The overall system is also referred as the TICK stack, containing four main components: *Telegraf*, *InfluxDB*, *Chronograf*, and *Kapacitor*.

IV. Conclusion

The flexible technological platform relying on IoT integration and independent, yet complementary, energy services aiming at increasing energy efficiency of individual consumers is proposed. The elaborated approach focuses towards cost-effective solutions and sustainable business models accounting for different levels of equipment and service deployment.

The underlying algorithms aims to estimate user regular behavior and anticipate wasteful practices, both in terms of energy and costs. Moreover, in order to support advanced wasting scenarios, the data collected at user premises are combined with the corresponding pricing/load/stability information received from the third party services (e.g. from ESCO, meteorological data service). In addition, integrated energy demand optimization is used to detect sub-optimal energy management of available energy assets in the multi-carrier environment. The integration of energy services is achieved through an IoT Cloud Platform and an open-source communication middleware enabling seamless data exchange of underlying systems and services.

The availability of professional, open-source, IoT solutions yields the opportunity for affordable and easily deployable energy management solution offered through innovative business models (e.g. SaaS) allowing for faster return on investment and higher benefits for the end Users.

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