A new distributed framework for integration of district energy data from heterogeneous devices

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A new distributed framework for integration of district energy data from heterogeneous devices

Francesco G. Brundu*, Edoardo Patti*, Andrea Acquaviva*, Michelangelo Grosso§, Gaetano Rasconà§, Salvatore Rinaudo¶, Enrico Macii*
*Politecnico di Torino, §ST-Polito s.c.ar.l., ¶STMicroelectronics s.r.l.

***Abstract*—The introduction of ”smart” low-cost sensing (and actuating) devices enabled the recent diffusion of technological products within the ”Internet of Things” paradigm. In a city district context, such devices are crucial for visualization and simulation of energy consumption trends, to increase the energy distribution network efficiency and promote user awareness. Nevertheless, to unlock the potential of this technology, many challenges have to be faced at district level due to the current lack of interoperability between heterogeneous data sources. In this work, we introduce an original infrastructure model, which efficiently manage and integrate district energy data.**

I. Introduction

It is now well established that Information and Communications Technologies (ICTs) play a key role in energy consumption monitoring and management. Recent research put focus on energy management at the city district level [1]. In fact, ICTs are essential (i) to profile energy consumption, (ii) to promote user awareness, and (iii) to optimize the demand response process. Further, tracing energy consumption at different levels of detail is crucial to increase distribution networks efficiency of a city district.

Pervasive computing is becoming essential to meet these needs, thanks to the availability of low-cost and autonomous wireless sensor and actuator nodes. However, it is necessary to (i) enable the interoperability between heterogeneous devices, (ii) provide an abstract view of the underlying devices, (iii) collect and integrate different kind of data, and (iv) define public APIs to allow further development. For this reason, we designed a novel infrastructure model, which handles transparently the retrieval and the integration of data coming from heterogeneous sources (both hardware and software), by means of an ontology. Data is then used to the purpose of simulation and visualization of energy behaviors, to optimize energy consumption in the district, providing feedback to end-users and increasing user awareness.

II. Infrastructure for district data integration

The use of different data sources, both hardware and software, requires the development of different interfaces. Middleware technologies and SOAs (Service Oriented Architectures) are crucial to the purpose of data availability through a common entry point, and have been used for instance in [2], [3]. To exploit data from different sources is, however, more difficult. In fact, several platforms and data formats are available, and there is a lack of interoperability between them.

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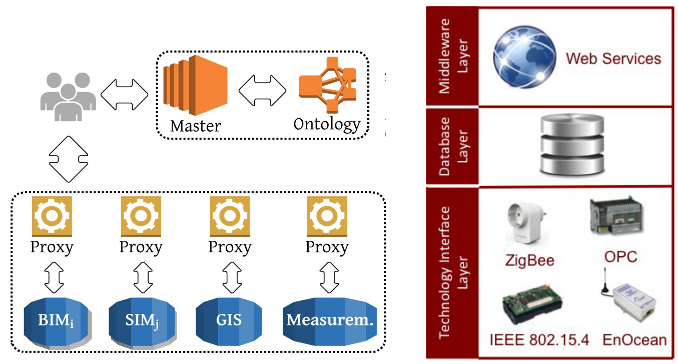

(a) Infrastructure schema (b) Device-proxy schema

Fig. 1. Depiction of the whole infrastructure (a) and the Device-proxy (b)

As shown in Figure 1(a), in a city district context there are different sources of data. For instance, there is a database for each building (obtained from each Building Information Model, BIM), and for each distribution network (System Information Model, SIM). On the other hand, there is one or more GIS (Geographic Information System) databases (which store georeferenced information about buildings in the district) and one or more measurements databases (which store data collected by sensors placed in the district).

Our model is designed to overcome the limitations imposed by data heterogeneity [4]. It is built upon the SEEMPubS infrastructure [5], which provides several components called proxies, used to create a p2p middleware-based network of devices for energy management at the building level. These proxies are built to interface each different data source (for instance, BIM databases or devices) of the system (see Figure 1(a)): They forward data requests to the source and return data responses translated in a shared common data format. Each data source is therefore accompanied with its specific proxy, which registers itself on a single master node. The master node is the unique entry point of the system, and it maintains an ontology of relationships between the different entities present in a district (e.g. buildings, sensors). It receives data queries from the users, refers to the ontology to get the interested data sources URIs, and redirects the users to the interested data sources. In this way the user, which wants to monitor a particular area, collects the related data from the returned URIs and integrates them, disregarding their origin.

We identified two different types of proxy: The Device-proxy (depicted in Figure 1(b)) and the Database-proxy. Device-proxies are designed to (i) abstract a device technology by means of a Web service, (ii) collect sensor data into a local database, (iii) publish data into the infrastructure (for instance to a global measurement database), and (iv) allow the remote control of actuator devices. They are composed by three layers: The lowest one is a dedicated layer, specific for the device; It collects data from the device in a local database, which is the middle layer. The highest layer is the Web Service one; It enables the remote management and control of the device and provides the interface to access the data. Moreover, this layer publishes the information in the middleware network by exploiting a publish/subscribe approach, which is a main feature of the SEEMPubS middleware [5]. Device-proxies were developed for IEEE 802.15.4, ZigBee and EnOcean protocols. Moreover, another proxy allows the interoperability with the OPC Unified Architecture, which provides backward compatibility with wired standards to the whole infrastructure.

BIMs, SIMs and GISs are usually exported to different kinds of databases. Database-proxies are necessary to translate different databases, each one encoded differently from the others, to a common data format. In fact, the union of different databases into a single one is usually not feasible, because of data format heterogeneity and conflicting values across different databases. Moreover, the management of such database would be difficult. For these reasons, we decided to use at the same time all the different databases, each one accompanied with its Database-proxy. Each proxy offers a Web Service interface which allows data retrieval and translation from its database to an open standard, such as JSON or XML.

Relationships between buildings, energy distribution networks and devices are stored in the master node of the infrastructure, using an ontology. The ontology depicts the structure of one or more districts, each one structured as a tree. The root node of each tree stores the global properties of the corresponding district (the name, the URIs of the GIS Database-proxies' Web Services, etc.). Under the root node, intermediate nodes represent buildings or energy distribution networks, with associated properties such as the BIM or SIM Database-proxy Web Service URI, or the mapping of the system in the GIS databases. Each intermediate node has associated leaf nodes, which represent the devices (for instance, sensors) placed in the corresponding entity of the associated intermediate node (building or energy distribution network).

When the end-user application queries the master node for a particular area of the district, the master node refers to the ontology and returns the URIs of the proxies' Web Services for the interested entities in the area (e.g. buildings), accompanied with additional information. Afterwards, the end-user application queries directly each returned proxy and retrieves the model and the data for each entity. In this way, the translation needed for the integration is carried out by each proxy and the end-user application can easily integrate the retrieved data, in order to build a comprehensive model of the interested area.

III. Development, commercialization and diffusion of enabling technologies

Proactive, coordinated actions between the various players in the "smart city" arena are key for the diffusion of the technological products and for the exploitation of the business opportunities. Hence, such distributed infrastructure is needed (i) to promote new services which exploit data from different sources and (ii) to enable the interoperability across heterogeneous devices placed in the district.

The envisioned improvements in quality of life and the optimization of infrastructures and energy distribution require the collaboration of technology providers, equipment manufacturers, infrastructure operators, standards organization and local and national governments. Data need to be available for users, distribution agencies and policy makers, by means of suitable ICT architectures; On the bottom of the pyramid, pervasive low-cost sensing (and actuating) devices and networks are required for getting information in the field and for local and real-time customization and application of energy management policies.

The basic components of "smart" sensing (and actuating) systems are microcontrollers (low-power, high-performance), communication devices (reliable and energy-efficient radio transceivers, e.g., Bluetooth Low Energy or sub-GHz), integrated low-cost sensors and actuators (MEMS-based) and energy storage and/or harvesting devices. Major device vendors products portfolio spans over all these categories, and works are ongoing for the development and optimized management of wireless sensors within the "Internet of Things" paradigm (based, e.g., on the 6LoWPAN, RPL and CoAP protocols). Special emphasis is placed on network self-configuration and energy consumption reduction, in order to increase system autonomy and minimize installation costs.

IV. Conclusion

Recently, more focus has been put to the development of a model for a city district area, in order to simulate and visualize trends and behaviors in energy consumption.

In this work, we proposed a new model for district energy consumption monitoring and management, which is scalable and easy to use. Buildings, energy distribution networks and sensors are abstracted from the user point-of-view and their data is available using Web Service technologies. Furthermore, the use of open standard data formats allows an easier integration of the retrieved data. The proposed solution aims to (i) manage data to profile energy consumption, from the whole city-district point-of-view down to the single building, (ii) provide a complete framework to optimize the energy waste, (iii) increase user awareness, and (iv) easily and efficiently manage the heterogeneous devices deployed in the district, and enable the interoperability between them.

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