IoT platform for Smart Cities: requirements and implementation case studies

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***Abstract*—Internet-of-Things (IoT) is considered as the key player to move forward the Smart City vision. Indeed, pervasive devices can enable a fain-grained monitoring of buildings and energy distribution networks. Thus, such information can be used to enhance energy optimization in our cities. However, interoperability among heterogeneous devices is a challenging task. Furthermore, all these IoT devices produce a huge amount of data that must be collected and post-processed, thus entering into the Big Data domain. Therefore, a distributed IoT platform for energy management has to be designed for i) enabling the interoperability among heterogeneous IoT devices and ii) handling such huge amount of data. In this paper, we describe the requirements to be addressed in order to develop an IoT platform for Smart City. We also present two distributed IoT platforms we developed to improve the energy management in Smart City. Finally, based on our experience in a real-world case study, we provide an estimation of the amount of energy-related information our presented platforms have to manage.**

Keywords—Smart City; Internet-of-Things; Software Architecture; Distributed Infrastructure; Big Data

I. INTRODUCTION

In order to move forward the Smart City vision, ICT (Information and Communications Technology) and IoT (Internet-of-Things) are recognized as key players [1] to enhance energy optimization in cities [2]. Therefore, real-time information about environmental characteristics and energy consumption can be accessed from pervasive and heterogeneous IoT devices deployed in buildings and across energy distribution networks. In this scenario, one of the main challenges imposed by IoT consists on enabling the interoperability across heterogeneous devices to build software infrastructure for cross-domain applications. This issue can be overcome thanks to middleware technologies that enable the interoperability across heterogeneous data-sources, either hardware or software, by providing an abstract view of their functionalities. Furthermore, considerable effort has been devoted to standardizing the communication among IoT devices [3], [4], as well as service interoperability layers and frameworks [5], [6]. However, building large-scale IoT platforms capable of integrating and adopting new standards remains challenging.

Once the interoperability is enabled, the energy-related information from heterogeneous devices can be collected and correlated into a common ”smart digital archive” for energy management of Smart Cities. In general, IoT technologies enable fine-grained monitoring of our cities, also in (near-)real-time. Therefore, an IoT platform for Smart City has to be prepared in receiving and managing huge amount of information, thus entering into the Big Data domain. Hence, they have i) to be highly available, ii) to scale up rapidly and iii) to provide a uniform interface to all deployed technologies.

In this paper, we present our experience in developing two distributed IoT platforms for energy management in Smart City. Such IoT platforms aim at providing a variety of applications involving different stakeholders to increase the energy efficiency of a city and foster new services. These platforms have been deployed in a real-world scenario and the city of Turin (Italy) has been selected as case study.

The rest of this paper is organized as follows. Section II reviews relevant background literature. Section III describes the requirements a distributed IoT platform has to address. Section IV introduces two IoT platforms for energy management in Smart City contexts and provides a comparison between them. Based on our experience in a real-world case study, Section V presents an estimation of the amount of energy-related information an IoT platform has to manage. Finally, Section VI discusses the concluding remarks.

II. RELATED WORK

In Smart City and Smart Grid scenarios, different software solutions have been proposed in literature to increase the energy management of our cities through pervasive monitoring. These solutions provide also innovative services to end-users. Kim et al. [7] presented a data-centric middleware for Smart Grid. It allows decentralized monitoring and control exploiting a publish/subscribe model [8] that is appropriate for delivering information but, in our view, is not yet sufficient to retrieve data without having to wait for new events. For this purpose, such software architectures should implement both publish/subscribe and request/response communication paradigms.

In our previous work, we presented a distributed software infrastructure for general purpose services in power systems [9]. The software architecture enables the interoperability across heterogeneous devices to manage a Smart Grid by creating a secure peer-to-per network. Further following this view, we proposed an architecture for integrating different data-sources to enhance the energy efficiency in heating distribution networks at district level [10]. It also provides tools for big data analysis to evaluate building energy consumptions [11] and increase the energy awareness [12].

The ReActOR system [13], is a middleware characterized by a tiny footprint and can be deployed as a service. It consists of three layers: i) the *Facade Layer* that provides Web Service, ii) the *Core Layer*, and iii) the *Extensions Layer* that gives support for different technologies. It enforces user authorization by mapping each user to set of devices to be managed. However, this middleware is limited to hardware devices and it does not support the integration of other different data-sources.

SemsorGrid4Env [14] is a service-oriented architecture to design open large-scale semantic-based sensor network applications for environmental management. It enables rapid development of thin applications and allows the integration of both realtime and historical data from heterogeneous data-sources. This solution is tailored to environmental management and cannot be applied seamlessly to a city.

Different research projects and initiatives contributed to define models and guidelines to foster interoperability between various application domains. The IoT-A project [6] provides an IoT reference model to allow the description of an IoT solution by using shared building blocks. It also provides a reference architecture and general advices to IoT architects. The OneM2M alliance [5] aims at developing detailed technical specifications for a common M2M Service Layer using existing IoT and Web standards. However, it does not cover many aspects of IoT platforms, such as scalability, availability and deployment. Finally, the FIWARE [15] research project aims at designing a service infrastructure for the Future Internet vision. Such infrastructure is composed by reusable components that can be selected and complemented with additional specific components.

With respect to literature solutions, we present two IoT software infrastructures for energy monitoring and management in Smart City: i) DIMMER and ii) FLEXMETER. DIMMER aims at enabling the interoperability across different devices, either wireless or wired, to access and share heterogeneous information about energy distribution systems, buildings and apartments in the district. Such information is also correlated to parametric virtual models of buildings and energy distribution systems with the purpose of providing a smart digital archive of the city. Make available these data is useful to characterize the energy consumption profiles from the single building up to the whole district or city in order to design more efficient control policies. FLEXMETER is a multi-service and multi-utility architecture that aims at facilitating the access of multiple actors to relevant energy related data to foster various innovative services. As DIMMER, it enables the communication across different devices in a Smart Grid scenario. In addition, FLEXMETER offers a cloud-based infrastructure to collect, analyse and provide energy information from various smart meters of different utilities such as electricity, water, heating and gas.

III. Requirements of IoT platform for Smart City

In order to address energy management in Smart Cities, a distributed IoT platform has to be scalable due to the huge amount of data it will receive and manage. In addition, such data are heterogeneous, so it needs to be flexible for collecting a huge amount of miscellaneous data. This means that an IoT platform will face Big Data domain challenges. On this premises, we identified the following main requirements to be addressed in order to design and develop distributed software architecture for IoT in Smart City contexts.

Interoperability among heterogeneous devices is a key requirement in order to enable communication and data transmission of IoT devices. Indeed, the resulting software infrastructure needs to integrate in the same environment different systems and technologies. For this reason, middleware is a valuable software instruments to enable the interoperability across heterogeneous devices and to abstract their functionalities.

An IoT platform has to implement features for *real-time data collection* from large number of different sensors to provide actual information about events or behaviours in the Smart City. Consequently, storage systems should scale horizontally to better address the data storing and access.

(Near-)Real-time data transmission is an important requirement that implies an asynchronous communication. This can be implemented by exploiting publish/subscribe approach [8], which is complementary to request/response. Publish/subscribe communication paradigm removes the interdependencies between producer and consumer of information. This paradigm fosters to develop distributed services that are independent from data-sources and can react in real-time to certain events.

Recent practices in building distributed applications and infrastructure promote a *microservice approach*. This is an emerging designing pattern that can be defined as *an approach to develop a single application as a suite of small services, each running in its own process and communicating with lightweight mechanisms* [16]. These services are *small, highly decoupled and focus on doing a small task* [17]. Hence, an IoT platform should be designed following the *microservice* patterns to increase its flexibility and maintainability.

An IoT platform needs to *expose Web Services and API* to access information, either raw or post-processed, exploiting open and *standard data-formats*. This is needed to foster the design and development of novel services. In this view, REST architectural principles promotes easy-to-use interfaces that are loose coupled of individual (low level) components. This is the foundation of modern distributed Web applications. Hence, REST coupled with the microservice approach helps in developing software infrastructure easy to manage and easy to use for developing distributed applications.

Finally in a Smart City view, providing *awareness to end-users* is a milestone. Indeed, user-friendly applications to interact with the pervasive IoT devices needs to be developed. For this reason, an IoT software infrastructure must be designed to facilitate this interaction between users and things. In addition, user feedbacks and actions could also be collected and used to build social behaviour models to foresee user attitudes for providing customizable user-centric services.

IV. IoT platforms for Smart Cities

In this section, we present two distributed IoT software infrastructures for Smart Cities that have been developed following the requirements described in Section III: i) DIMMER and ii) FLEXMETER.

A. DIMMER platform

DIMMER (namely *District Information Modelling and Management for Energy Reduction*) is a distributed IoT software infrastructure to collect and correlate heterogeneous energy-related data into a distributed smart digital archive for district management. It aims at providing tools to reduce both energy consumption and CO_2 emissions by enabling more efficient energy policies that account for real characteristics

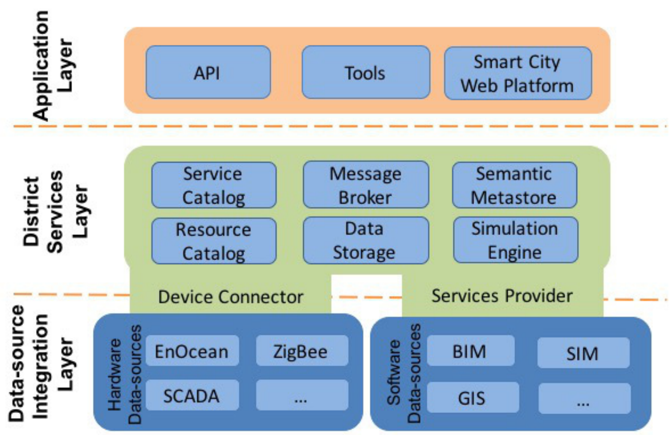

Fig. 1. DIMMER platform schema

of the district and its buildings. Therefore, DIMMER exploits a microservice approach to build a virtual district information model by providing the following features:

- enable the communication among heterogeneous IoT devices and technologies;
- collect (near-)real-time data coming from IoT devices deployed in buildings and along distribution networks (e.g. heating and electrical networks) in the district;
- correlate and post-process such data among them;
- correlate energy-related information with BIM (Building Information Modelling) 3D parametric models, GIS (Geographic information system) and SIM (System information Model);
- simulate innovative energy control strategies, for both electrical and heating systems, taking into account also renewable sources. Such simulation can also exploits real data and BIM models as input;
- visualize district-level energy usage and structural parameters of buildings and systems.

In addition, DIMMER aims at promoting the sharing of data among different actors and stakeholders playing in Smart City scenarios.

As shown in Figure 1, DIMMER is a three-layered distributed infrastructure that provides both request/response and publish/subscribe communication paradigms. It is built on top of LinkSmart middleware [18], which provides features for integrating heterogeneous IoT devices. DIMMER consists of: i) *Data-source Integration Layer*; ii) *District Services Layer*; iii) *Application Layer*.

The **Data-source Integration Layer** integrates heterogeneous hardware and software technologies into the platform through the *Device Connector* and the *Services Provider* respectively. The *Device Connector* integrates a certain IoT device by abstracting its functionalities into Web Services regardless of its low-level technology. In addition, it can work also as publisher and/or subscriber for all the IoT devices it manages. The *Service Provider* integrates different software data-sources (i.e. BIM, GIS and SIM) by providing Web Services to access the information.

District Services Layer is composed of different middleware-based components providing services at district level. The *Service Catalog* provides an index of all the available services in the DIMMER platform. The *Resource Catalog* exposes to applications the list of the available IoT devices and resources. Hence, when a new middleware-enabled service is available, this needs to register itself to Service Catalog. Similarly, when a new IoT device is available, the Device Connector (that integrates it in the platform) has to register it to Resource Catalog. Thanks to these two Catalog modules, the infrastructure is able to automatically manage all the integrated services and IoT devices and expose them to other application. *Message Broker* provides an asynchronous communication through MQTT [3], which is a communication protocol for publish/subscribe [8] to send data in (near-)real-time. In addition, this approach increases the scalability of the whole infrastructure [9]. The *Data Storage* is in charge of collecting data sent by IoT devices deployed in district. The DIMMER platform has been designed also to integrate already existing databases regardless of their technology and owned by other actors or stakeholders. This allows the platform in integrating a set of different databases that can work together and transparently export stored information through Web Services. In addition, the *Data Storage* is able to collect and provide other kind of information not strictly related to IoT devices, such as end-users feedbacks or energy distribution schedule settings. The *Semantic Metastore* provides a semantic description of the entities in the district enriched with additional attributes and relations to other entities exploiting semantic web technologies (i.e. ontologies) [19]. The *Simulation Engine* provides features to simulate energy optimization policies exploiting information from other DIMMER components. Therefore, novel control policies at building and district level can be simulated to evaluate their impacts using historical and real-time data correlated with BIM and SIM models.

Application Layer provides users with set of tools and API to manage, post-process and visualize data coming from the lower layers. To increase user-awareness, this layer provides a web portal and mobile applications to address the needs and requirements of different stakeholders. Information are also shown exploiting both Virtual and Augmented Reality.

B. FLEXMETER platform

FLEXMETER is a flexible smart metering architecture for smart cities. It is a distributed IoT platform that collects and integrates heterogeneous information from multiple energy vectors (e.g. electricity, water, gas and heating) to foster innovative services to end-users. In this view, the platform is in charge of: i) integrating different devices; ii) correlating data from smart meters of different utilities; iii) providing advanced services to end-users (i.e. consumers, prosumers and Distribution System Operators); iv) enhancing the retail market. It aims at enabling:

- real-time readings management;
- real-time accounting activities management;
- real-time information to customers through a suitable interface structure;
- detection energy thefts;
- near-real-time grid level and user level fault detection

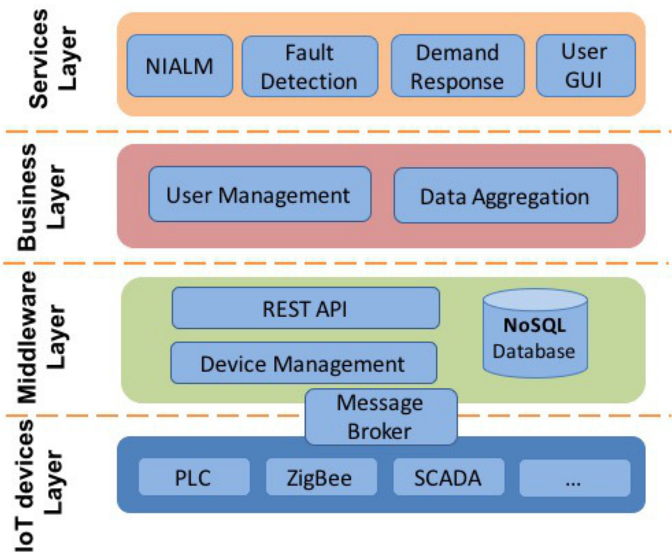

Fig. 2. FLEXMETER platform schema

allowing optimal alarming and first intervention systems to be adopted;

- demand response together with optimal integration of distributed generation and storage systems.

FLEXMETER has been designed following the microservice patterns. As shown in Figure 2, it is a four-layered distributed architecture that exploits, as DIMMER platform, both request/response and publish/subscribe communication paradigms. It consists of: i) *IoT Devices Layer*; ii) *Middleware Layer*; iii) *Business Layer*; iv) *Services Layer*. Its core has been developed starting from SiteWhere platform [20], which has been extended to address FLEXMETER objectives. SiteWhere is a multi-tenant and multi-protocol open platform for Internet-of-Things.

The **IoT Devices Layer** consists of IoT devices (i.e. heterogeneus smart meters) integrated into the platform that send data via the Message Broker exploiting the MQTT protocol [3].

The **Middleware Layer** is based on SiteWhere and provides features to manage devices, collects information in scalable NoSQL or time-series databases (e.g. MongoDB or InfluxDB respectively) and access them through REST API. Among the management of devices, this layer also provides features to self register new devices and expose its resources to applications.

The **Business Layer** post-processes data by aggregating (per minute, hour, week, month) and storing them in time-series. In addition, it manages users by authenticating them and associating their profiles to energy-related information.

Finally, the **Services Layer** exposes modules to address energy flows management and user awareness. Indeed, the algorithms running in this layer are devoted to demand-response and fault detection that may occur across the entire energy distribution network. It implements also Non-Intrusive Appliance Load Monitoring (NIALM) [21] services to disaggregate energy consumption of appliances from the aggregated data acquired by a single point of measurement (i.e. smart meter). To visualize such information, this layer provides GUI (Graphical User Interface) via a web portal and mobile applications that increase user awareness about energy consumption.

C. Comparison between DIMMER and FLEXMETER platforms

In this section, we compare the two presented IoT software infrastructures for Smart Cities. As shown in Table I, both DIMMER and FLEXMETER are in charge of receiving and managing a huge amount of data coming from IoT devices deployed in building and energy distribution systems across the city. Hence, data storage and management is a key issue. DIMMER has to manage and correlate heterogeneous data also regarding structural parameters of buildings (BIM), distribution network (SIM) and georeferenced information (GIS). For this purpose, we designed the platform to manage different databases and export data through web services. In this view, each stakeholder playing in a Smart City scenario can share its information by including its databases into the DIMMER network. In addition, DIMMER exploits semantic web technologies to provide semantic description of entities in the city (e.g. devices, building and systems) and to better correlate information between them about BIM, GIS, SIM and measured data [19]. On the contrary, FLEXMETER is in charge of managing various time-series data from IoT devices (i.e. smart meters) about electricity, heating, water and gas. Hence, the platform includes a single point databases manager to store data in time-series and/or NO-SQL databases (e.g. MongoDB or InfluxDB) that provides scalability features for Big Data analysis and management.

As shown in Table I, both platforms has been developed following a microservice approach [16] to increase flexibility and maintainability by developing small services focused on doing small tasks [17]. DIMMER extends the LinkSmart middleware and creates a network of distributed software running on different servers and/or computers across the city. Viceversa, FLEXMETER has been designed as a single instance that can optionally run in a cluster of servers allowing multi-tenancy. A tenant refers to a group of customers with shared common access and privileges to software instance. Multi-tenancy software infrastructure is a single instance of software that serves various tenants by providing to each tenant a dedicated share of the same software instance. FLEXMETER multi-tenancy also allows separate data storage and processing pipelines.

Finally, DIMMER and FLEXMETER exploit both request/response and publish/subscribe communication paradigms and provide third-party actors with REST API to foster new services.

V. Estimation of Energy Information for the Turin Case Study

As mentioned in Section IV, both DIMMER and FLEXMETER platforms has been designed to receive a huge amount of data from several IoT devices deployed in a urban city context. Both platforms are deployed in Turin (Italy) to perform tests in a real-world environment. DIMMER platform is fully operating, while FLEXMETER is still under deploy-

TABLE I. COMPARISON BETWEEN DIMMER AND FLEXMETER PLATFORMS

Platform	Data-sources				Software Architecture features						Communication Paradigms	
	Measurementes from IoT devices	BIM	SIM	GIS	Microservice	Multi-tenant	Distributed	Semantic web technologies	Built-in simulation engine	API for third-party actors	Request/Response	Publish/Subscribe
DIMMER	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
FLEXMETER	✓				✓	✓				✓	✓	✓

TABLE II. AMOUNT OF SAMPLED DATA PER DAY IN TURIN

Utility	number of samples	sampling time	number of smart meter	bytes per day	DIMMER	FLEXMETER
Heating	50	5 min	5.6 k	5 GB	✓	✓
	50	1 h				
Water	5	1 h	300 k	2.3 GB		✓
Gas	10	24 h	300 k	0.2 GB		✓
Electricity	10	15 min	500 k	31 GB	✓	
	10	1 s		27 TB		✓

ment. In this Section, we present the amount of information (in terms of Gigabytes per day) both platform have to manage for a city like Turin that counts around 890 thousand inhabitants. Both platforms are designed to receives heating and electrical data sent by IoT devices deployed in buildings and distribution networks. FLEXMETER manages also information about water and gas distribution networks.

As shown in Table II, in Turin the heating network serves around 5.6 thousand buildings. Each building is equipped with IoT devices that send 50 samples every 5 minutes to monitor the energetic parameters and other 50 samples every hour to monitor distribution network parameters. Based on already collected data, every day both IoT platforms have to receive and store around 5 Gigabytes of information.

Regarding the water distribution network, in Turin there are around 300 thousand meters. In our case studies, we adopted smart meters that send 5 samples every hour. Considering to deploy these new meters in the whole city, the FLEXMETER platform have to manage 2.3 Gigabytes of data per day.

Similarly to water distribution network, the gas distribution network in Turin includes about 300 thousand meters. In FLEXMETER, we are integrating new smart meters that send 10 samples every day. Thus, replacing the old meters with the new means that the FLEXMETER platform handles 0.2 Gigabytes per day.

Finally, we need to distinguish two different cases for the electrical energy consumption. Indeed, depending on services to provide, the sampling time can change. In DIMMER, we correlate electricity data to BIM (Building Information Modelling) and SIM (System Information Models) to develop new control strategies for demand-response and perform simulations. In this case, a sampling time in the range of 10 or 15 minutes is enough. In Turin there are about 500 thousand meters, replacing them with novel smart meters that send 10 samples every 15 minutes, 31 Gigabyte per day have to be stored in the DIMMER platform. On the other hand, FLEXMETER aims at providing also services about fast fault detection and NIALM. In this second scenario, a sample rate of 1 second is needed. Thus in Turin, 500 thousand meters, sending 10 samples per second, produce about 27 Terabytes of information par day to be managed by FLEXMETER platform.

In conclusion, in urban energy contexts next Smart Cities have to be equipped with scalable and distributed IoT platforms. Indeed, depending on the services to provide, the amount of managed information will be in the order of Gigabytes or Terabytes per day.

VI. CONCLUSIONS

In this paper, we discussed the main requirements a distributed IoT platform for Smart City has to address. We also presented DIMMER and FLEXMETER, which are two IoT platform developed to provide services regarding multi-energy flows. We also discussed the impact, in terms of gigabytes/terabytes, a massive deployment of IoT devices in a city like Turin can have and consequently the amount of energy-related information the presented platforms have to handle.

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