Chapter 1
The Cloud of Things empowered Smart Grid Cities

Stamatis Karnouskos

Abstract The emergence of the Smart Grid era fuels a new generation of innovative applications and services that are build upon fine-grained monitoring and control capabilities pertaining the underlying infrastructure, such as that of future Smart Cities. Collection, processing and analytics on the Internet of Things massive generated data, as well as potential management functions will emerge; therefore making informed real-time decision making as well as its enforcement in a timely manner over complex infrastructures a reality. The prevalence of the Cloud and its services, can very well complement the Internet of Things when it comes to massive data management, giving rise to the Cloud of Things (CoT). For the next generation applications, the CoT can enable access to generic multi-modal energy services, on-top of which development of more sophisticated solutions can be realized. We depict here such Smart Grid services for the Smart City of the future, as well as experiences from their realization.

1.1 Introduction

We witness a revolution that capitalizes on the Internet as well as the prevalence of networked (embedded) devices (ranging from simple ones such as sensors to complex systems) in order to empower a new generation of innovative anytime–anywhere services. The "Internet of Things" (IoT) [13] revolution enables unprecedented interconnection of networked embedded devices that

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Stamatis Karnouskos
SAP Research, Vincenz-Priessnitz-str.1, D-76131, Karlsruhe, Germany
e-mail: stamatis.karnouskos@sap.com

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further blur the line between the real and virtual world. The upcoming industrial revolution expectation heavily depends on these smart devices [14], while their benefits can become tangible in key innovation and economic growth areas such as Smart Cities, energy, industrial automation, health, aviation [1].

Predictions of 20–50 billions of connected devices by 2020 exist [28], while according to Gartner [35] "…over 50% of Internet connections are things. In 2011, over 15 billion things on the Web, with 50+ billion intermittent connections. By 2020, over 30 billion connected things, with over 200 billion with intermittent connections. Key technologies here include embedded sensors, image recognition and NFC.". These highly interconnected devices constitute the backbone of modern critical infrastructures, a representative example of which is the energy and more specifically the emerging Smart Grid [12, 17].

Integrating, interacting and meaningfully taking advantage of the benefits of infrastructures composed of vast numbers of such smart devices, is not trivial and several considerations need to be tackled. Integration requirements [21] reveal the direct [19] or via middlewares [9] coupling of smart devices such as sensors and actuators [31] with other systems and services. Even with the basic aspects of integration addressed, more complex ones at system of systems level [29], such as security, trust, privacy, reliability, management, etc., may become more critical [17], especially in the light of impact in real-world (due to the strong coupling of these devices for monitoring and control purposes in the physical world).

The Smart Grid vision [7, 8] goes beyond current efforts for smart metering (which focus mostly on fine-grained monitoring) and in the long run promises real-time decision making which may provide innovative solutions in energy management, sophisticated demand-response (DR) and demand-side management (DSM), optimal resource usage, reliability and security, new business opportunities etc. [23, 33, 38]. The core of Smart Grid depends on the usage of modern information and communication technologies [26, 43] that will enable real-time bidirectional communication with all (old and new) participating stakeholders. This will lead to the enhancement of existing processes but more importantly will enable a new generation of cross-layer collaborative services and the realization of applications that are not possible or affordable today [15].

The Smart Grid and its services are seen as an integral part of the Smart City of the future. Several ongoing efforts [10] strive towards capitalizing on the hyper-connected information infrastructure [26] and the collaboration [15] among the things, services, and systems expected to exist in the Smart City. Examples of them include real-time multi-channel energy monitoring [24], better energy coordination to take advantage of excess renewable energy or minimize costly peaks, usage of existing infrastructure such as the public lighting system for energy management and additional revenue generation

[23, 32], engagement of electric vehicle fleets as well as other sources that could act as flexible energy storage etc.

Increasingly it becomes evident that the capability of real-time monitoring and management offered by the Internet of Things can have a significant impact on the Smart Grid [43] and its applicability in Smart City scenarios. However, the network effects [6] can only be capitalized upon, if an open infrastructure is in place where its layers can evolve independently. In this work we focus on shedding some light on emerging trends and the game-changing aspects they bring. As a example case, we will refer to the efforts within the NOBEL project [30] which has prototyped such an energy service-based infrastructure [18, 20, 22–25] and point out some key aspects for the future Smart Grid City.

1.2 The Cloud of Things empowered Smart Grid

The prevalence of increasingly intelligent networked devices and systems in business and private homes sets the basis for a high degree of energy monitoring. This coupled with open formats for describing the data and exchanging it with other systems will enable their massive processing and empower sophisticated management mechanisms. Although at the “edge” of IoT multiple communication technologies might be used (e.g., ZigBee, Bluetooth etc.), at some level while the information flows towards Internet connected systems. IP support is offered nowadays at device level [19, 40], even when we speak about very resource constrained devices. As an indicative example for the latter we point to GreenWave Reality’s (`www.GreenWaveReality.com`) WiFi-aware light bulbs that can be controlled by other devices such as smartphones.

Although today “smart meters” still refer to the enhancement of the legacy meters with modern Information and Communication Technologies (ICT), the prevalence of IoT means that probably any kind of networked device be considered as “smart meter” as it will be able to offer monitoring and control capabilities including information on the energy consumption and/or production. It may even go further offering additional info on current state and potentially task-specific energy signature adjustment capabilities for appropriate energy-wise task rescheduling. This is potentially a game-changer, especially in highly-automated environments, since now we will be able to know at very fine-grained level energy information that can flow into enterprise systems, calculate accurately the energy impact of business processes and optimize them dynamically considering a wide range of criteria such as environmental or financial impact etc.

Figure 1.1 depicts the paradigm change and the transition towards a Cloud-based IoT i.e. the Cloud of Things (CoT) [20] when considering the Smart Grid. Appliances (equipped with networked embedded systems) that

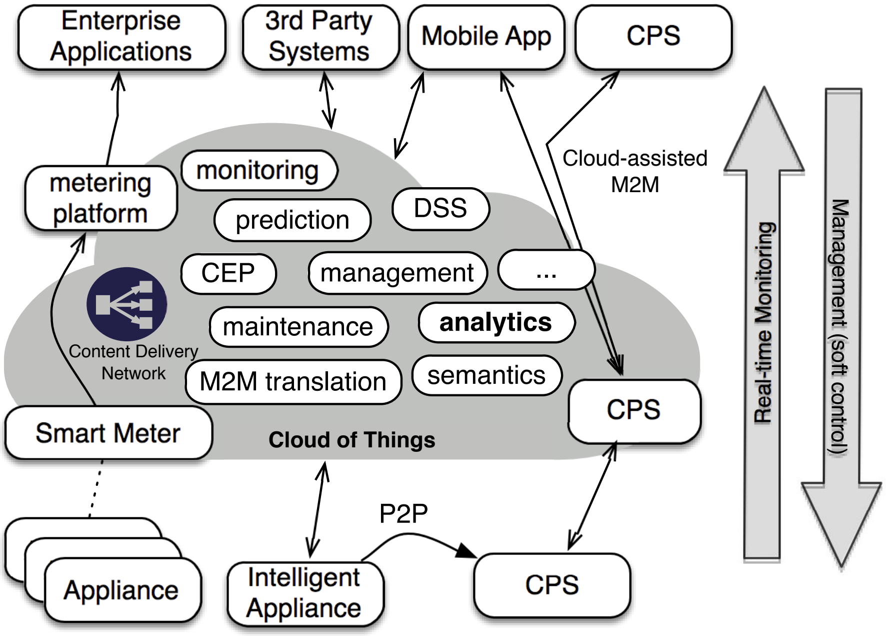


Fig. 1.1 The Cloud of Things in the Smart Grid context

are able to communicate (mostly) wireless, will be able to integrate, interact and cooperate [15] in, both P2P manner as well as via Cloud-based auxiliary services. This indicates that the "edge" devices which are usually resource-constrained, can now complement their capabilities with much more "powerful" ones running on the Cloud, thereby enhancing their own functions. Being able to attach to global infrastructure services and bidirectionally interact with them will boost the information exchanged among the virtual and physical world and will greatly benefit applications depending on their fusion.

The capability of not only offering the information acquired (provisioning) but also consuming information that may enhance their own operations leads to the enhancement of IoT edges (that were hardly possible before due to the increased resources required or a system-view not available at the edge), and optimisations at system level e.g. in a building, an enterprise, or even a smart grid city. A typical example of information provisioning would be the real-time measurements offered by "edge" devices e.g. to a Cloud-based monitoring service. These can be energy measurements as well as device operation measurements which due to the rich Cloud resources available, can be analysed and decisions can be made for device specific actions (e.g. remote maintenance) as well as global actions, e.g. massive control of the consumption or generation systems. This enables new highly-scalable approaches that were previously not possible or too costly to realize; for instance avoiding blackouts by massively reducing energy consumption or rescheduling or adjusting specific categories of non-critical devices (e.g. household appliances) while giving higher priority to sensitive locations such as hospitals.

As discussed, the benefit of utilizing the Cloud of Things is that additional capabilities potentially not available at resource constraint devices can now be fully utilized taking advantage of Cloud characteristics such as virtualisation, scalability, multi-tenacy, performance, lifecycle management etc. The manufacturer for instance can use such Cloud based services in order to monitor the status of the deployed appliances, make software upgrades to the firmware of the devices, detect potential failures and notify the user, schedule proactive maintenance, get better insights on the usage of his appliance and enhance the product etc. At smart grid city level, seamless monitoring and adjustment can be done for public infrastructure to comply with the goals pursued.

The fusion of information from the business (virtual) and physical (real) world are key in achieving innovation and efficiency. The Cloud of Things makes it possible that information, generated at highly distributed points in the real world, is now available offering high visibility to aspects that were not measurable at affordable costs before. Such massive data often referred to as “Big Data” can now be collected and analysed in the Cloud, and potentially enhance decision making processes. Customized analytics can be offered to a plethora of end-devices in various forms, e.g. of the individual user or in custom-aggregated form via content-delivery-networks. The latter has the potential to empower a new generation of services that are more accurate, near real-time, and can be applied at large scale. A typical example scenario in Smart Cities would be the monitoring of Key Performance Indicators at city- or neighbourhood-wide level that pro-actively enables tackling of issues and also enhances city planning processes.

The “Big Data” acquired can be enriched with context-specific and system-wide aspects as well as business relevant information in the Cloud and enable us (e.g. through analytics) to better understand the physical world, its processes, the impact on the business side and eventually take more informed decisions. Although “Big Data” existence and analytics don’t necessarily guarantee better decisions, potential new insights that may be acquired, may materialize to more effective problem tackling and business advantages. As an example, in the Smart Grid, analytics empower scenarios [10] of grid infrastructure optimization, energy management scenarios (such as demand-response schemes) with participation of residential prosumers (energy producers and consumers), energy trading, better planning of energy infrastructure in cities etc. Big data analytics is seen also as the key into understanding complex system of systems, such as the emerging Smart Cities. For instance the SmartKYE project (`www.smartkye.eu`) aims at enabling municipalities to better understand and manage aspects of a Smart City via a business cockpit, by relying on analytics that can be queried over a distributed infrastructure of energy management systems (EMS) and their combination with business information as well as goals.

The existence of the Cloud of Things, will constrain the need for on-premise middleware and proprietary solutions. New service providers will flourish and value added services will be created such as real-time energy monitoring, real-time billing, direct asset management, customized information services, marketplace interaction etc. This is a significant shift for the energy domain, as we move away from heavyweight monolithic applications towards much more dynamic, up-to-date and interactive ones utilizing local capabilities. By increasing visibility via near real-time acquisition and assessment of the energy related information, providing analytics on it and allowing selective management [39], we expect the emergence of a new generation of customized energy efficiency services offered potentially even at smart grid city level [22, 25].

1.3 Envisioned Smart Grid City Energy Services

Although the IoT and is an area of high interest in industry, we have still to reach common understanding even for matters such as what a smart meter should offer, i.e. “basic services” to be offered by all smart meters or even data formats for open communication of the acquired data. The same holds true for any potential “basic” management capabilities that the smart meter should have in order to be able to take the envisioned role in the Smart Grid ecosystem [20]. Generally, although there are several efforts and prototypes, the Internet of Things lacks even the basic standardized API for interaction among its components i.e. the devices themselves as well as between the devices and higher systems and services. The key message is clear: To be able to capitalize on the IoT/CoT, we need to establish a common minimal base and offer basic services upon which more sophisticated approaches can be built.

As already discussed, we expect several energy services to exist in the future Smart Grid infrastructure that can be integrated into applications and traditional systems in order to enhance their functionality [18]. These services can then be integrated into applications and other mash-up services and be part of a larger Smart City ecosystem. Examples would include:

- *Timely Energy Monitoring* is expected to be a reality, especially when considering the vast investments in smart metering projects [10]. Information acquired at several layers of the Smart Grid infrastructure can be validated and securely communicated among the different systems and the Cloud-based services at (almost) real-time tempo.
- *Fine-grained Control/Management* capabilities are expected to complement existing scenarios of adaptive management of the infrastructure. This implies potential understanding of the underlying processes to a certain

extend and flexibility of the energy consumption/production that can be negotiated; hence goes beyond simple ON/OFF signals and consider the whole lifecycle of affected devices and systems as well as their operational context, involved processes and goals locally and at system level.

- *Energy Brokering* [11] may be seen as a value-added service with the help of which financial management (soft-control) can be applied to the Smart Grid infrastructure. Although this is still at early stage, the implications for applications build around it could have a significant impact on the dynamic operation of the grid, as well as the offering of new innovative services and applications for all stakeholders [18].
- *Real-time Analytics* are expected to operate on the "Big Data" provided by the plethora of Smart Grid City stakeholders. Effective assessment of data will provide new insights on the existing operational aspects and unveil optimization opportunities. Additionally, informed decision making considering real-time data on an unprecedented scale will be possible, which may lead to better decisions and future planning for Smart Cities.
- *Community Management* services will provide customized information adjusted to the goals of the specific community, e.g. a neighbourhood within a Smart City, and hence actively enable a critical mass of prosumers in the Smart City. The communityware Smart Grid [16] must support the creation of dynamic communities where the (mobile) user may connect and participate with its assets (e.g. electric vehicle, white-label appliances etc.). These communities may be motivated by several aspects, e.g. environmental, economic, social etc. Support for intra- but also inter-community collaboration is wished in order to increase network effects.
- *Energy Application Stores* will be required to manage the large number of energy related services and applications available for the Cloud of Things enabled devices. There users/devices may automatically find, install and maintain a variety of energy related applications and services that may enhance their operational context.

As an example of emerging services the NOBEL project [30] has realized energy monitoring, management and energy brokering services Figure 1.2. Others such as BeyWatch [34], OpenMeter (`www.openmeter.com`), AIM [37], DEHEMS [36], BeAware [2], MIRABEL [41], ENERSip [5] and SmartHouse/SmartGrid [27] focused on intelligent device integration for energy monitoring, and complementary factors such as price-driven control, forecasting and scheduling. Similar efforts exist also in various other R&D projects [10]; however the real-time analytics, community support focus, and addressing of large-scale real-world infrastructures seem to be still at a very early stage. Recently projects such as the SmartKYE (`www.smartkye.eu`) were initiated with the aim to tackle the area of better decision making for municipalities based on analytics and interaction with the Smart City energy management infrastructure based on Cloud services and distributed data queries.

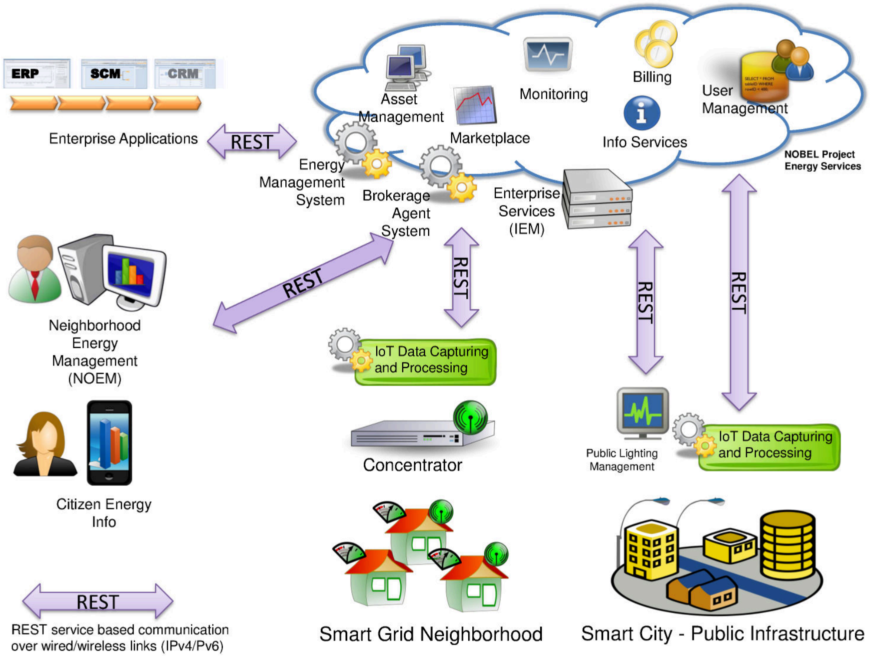


Fig. 1.2 Energy Service Infrastructure: the NOBEL project approach

1.4 Realization Example: The NOBEL Energy Services Platform

The NOBEL [30] vision builds upon the expectation that the future energy monitoring and management system will be in close cooperation with enterprise systems. Enterprise services will integrate information coming from highly distributed smart metering points in near real-time, process it, and take appropriate decisions. This will give rise to a new generation of mash-up applications that depend on "real-world" services which constantly hold actualized data as they are generated.

The NOBEL project has taken up the challenge to design, built and pilot an open energy services platform, i.e. the Enterprise Integration and Energy Management System (IEM) [22, 25] as depicted in Figure 1.3. The approach was driven by the wish to enable lightweight Internet accessible energy services for thin clients over multiple channels, thus lowering the integration and application development costs.

As proof of concept a common set of energy services has been realized, and offered to all stakeholders externally and internally to the platform via lightweight RESTful services. More specifically these were accessed by a web application, various mobile applications realized in android devices, enter-

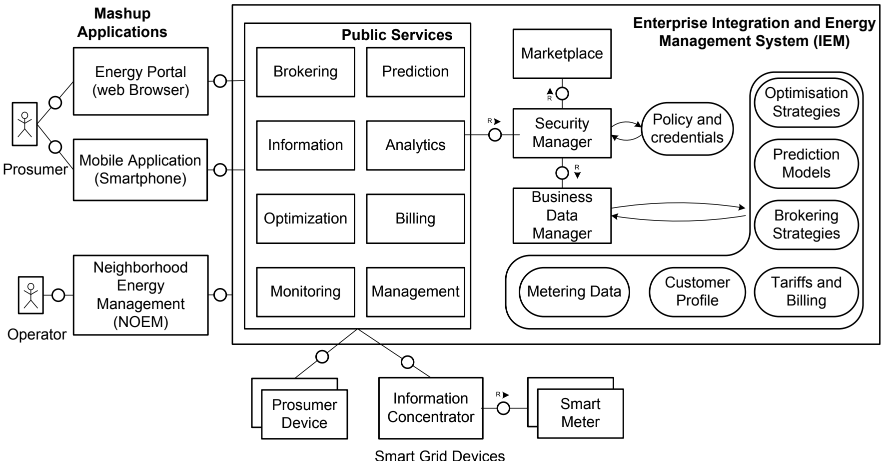


Fig. 1.3 Overview of the IEM architecture [22]

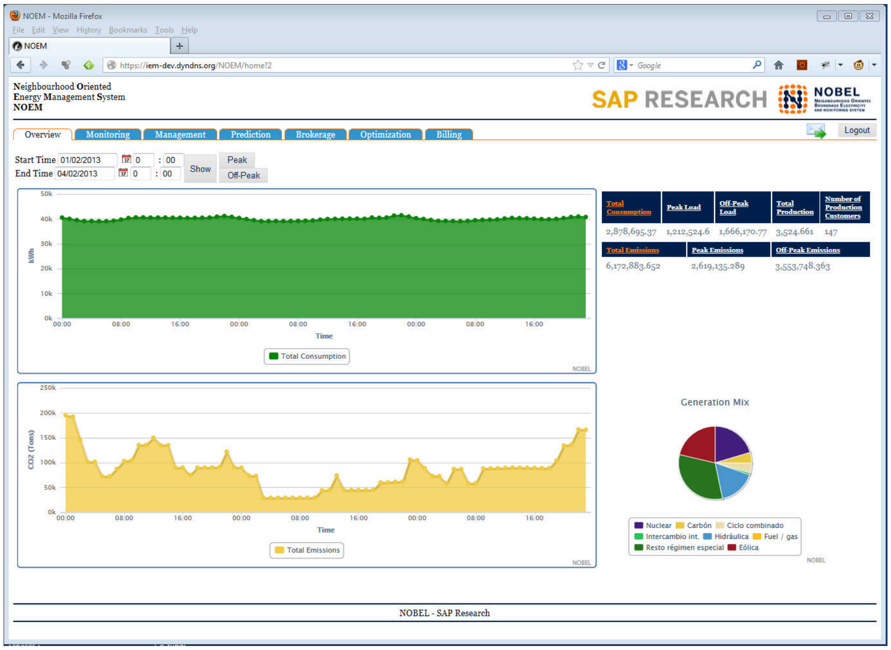
prise systems and smart meters / smart meter concentrators. Based on this common set of available public APIs, a variety of services were built and piloted [24, 25].

In a Smart City, numerous systems (including potentially individual devices) may connect directly or indirectly (e.g. via gateways) to the services provided by the IEM. As seen in Figure 1.3, there are several architecture parts such as the device layer, the enterprise services and end-user mash-up applications. On the IEM service layer, one can mash up services to provide customized functionalities for various applications, such as an energy portal (accessible via web browsers), mobile applications, or a neighbourhood energy management centre (NOEM) [24]. Furthermore, enterprise services process the collected data and provide advanced functionalities such as validation, analytics, and business context specific processing.

The following services have been realized and assessed [22, 25]:

- *Energy Monitoring* for acquiring and delivering data related to the energy consumption and/or production of prosumer devices.
- *Energy Prediction* for forecasting consumption and production based on historical data acquired by IEM and other third party services (e.g. weather data).
- *Management* for handling the asset, user and configuration issues in the infrastructure.
- *Energy Optimization* for interacting with existing assets of the Smart City (as a proof of concept a public lighting system [23]) and enable better usage of the energy available at neighbourhood level.

- *Brokerage* offering energy trading to all prosumers citizens who, in a stock-exchange manner, could interact via the platform and buy potentially cheaper energy or sell excess production from their photovoltaic panels.
- *Billing* which offered real-time view of the energy costs and benefits (from transactions on the Smart City energy market); hence avoiding "bill-shock" scenarios.
- *Other* value added services offering bidirectional interaction between the users and the energy provider such as notification for extra-ordinary events etc.



Start Time 01/02/2013 0 : 00
End Time 04/02/2013 0 : 00

Total Consumption	Peak Load	Off-Peak Load	Total Production	Number of Production Customers
2,878,695.37	1,212,524.6	1,666,170.77	3,524.661	147

Total Emissions	Peak Emissions	Off-Peak Emissions
6,172,883.652	2,619,135.289	3,553,748.363

Fig. 1.4 Smart City cockpit showing city-wide demand, CO_2 and energy mix [24]

The RESTful web services offered by the IEM platform were designed for high performance and their API was conceived to cover the needs of the heterogeneous stakeholders accessing them. The REST adoption imposes some architectural style selections, e.g. client-server separation of concerns, stateless interactions, uniform interfaces and a layered system. An example of Smart City wide functionality shown to the city officials is depicted in Figure 1.4. There a high level view of the energy production and consumption by aggregating all device measurements is provided, including some additional information such as the generation mix.

The platform (IEM) as well as example applications (e.g. NOEM) have been extensively tested and used in a pilot [24, 25] in the second half of

2012 as part of the NOBEL project pilot which took part in the city of Alginet in Spain. Data in 15 min resolution of approximately 5000 meters were streamed over the period of several months to the IEM, while the IEM services were making available several functionalities ranging from traditional energy monitoring up to futuristic energy trading.

1.5 Considerations for Smart Cities

The hands-on experiences with the design, prototyping and piloting of the IEM and NOEM have revealed several technical aspects that should be given attention prior to productively deploying such systems [24, 25]. Apart from these however, high-level lessons were also acquired that could serve future Smart City stakeholders in their efforts to develop the next generation of services and applications in the Cloud of Things empowered Smart Grid.

The evolution on the infrastructure (either by retrofitting or by replacement) with the new IoT capable systems) has several challenges [4] and we will see a stepwise evolution with varying degrees of IoT-enabling technologies deployed in different parts of the Smart Cities. All these will be owned by a different stakeholders, hence the focus should not be on tightly integrated and “island”, task- or process-specific only solutions, but rather on having the bigger picture in mind. The latter implies as key design criteria openness and compliance to standards, as well as focus on collaboration [31] and interaction/communication potentially in a service-oriented lightweight way. Therefore, design and deployment of Smart City wide services should be extensible and easily enable integration in future scenarios.

The Cloud of Things is seen as an integral part of future Smart Cities. Although IoT today focuses on the communication part among the different “things”, the CoT makes some assumptions on the communication layer, e.g. focusing mostly on widely accepted web technologies (without excluding of course others), and integration with the Cloud in order to take advantage of its capabilities such as virtualisation, scalability, multi-tenacy, performance, lifecycle management etc. The differentiating part here is the “outsourcing” model where the edge of IoT is used for monitoring and control aspects but “heavyweight” processing can be moved from the edges to the network (i.e. the Cloud) and hence combine the best of both worlds. In the next decades with the advances in hardware capabilities of the edges, the Cloud of Things might be able to migrate closer to them (i.e. the devices) and hence it should not be treated solely with the view we have today about it i.e. running exclusively on huge centralized data-centres.

With the enhanced monitoring capabilities at IoT layer as well as the increased access and correlation with enterprise data, the era of IoT “Big Data” reaches the Smart Cities. This has profound implications on the applications and services depending not only on the processed outcome of the data but also their quality and timely acquisition. To this end, e.g. validation of data values and syntax based on model semantics, correct time-stamping, duplicate detection, security validation and risk analysis, anonymisation, data normalization, estimation of missing data, conversion to other formats or models etc. may be necessary prior to release of the data for further processing or consumption. Scalable data management [42] supporting acquisition, processing and customized consumption by a multitude of devices is key to the success.

As this is a complex system, any pitfalls may propagate and lead to high-impact system-wide problems e.g. with financial impact, prediction estimations, operational hazards etc. As the Smart City will not only monitor but also manage (control) its assets, the development of these safety-critical applications will be increasingly challenging. Since they will depend on various services (under the control of various stakeholders) it will be difficult to do systematic testing and hence safety and resilience has to be a priority [17].

The Smart City infrastructure and its services are expected to continuously evolve. Hence there is need for robust services identified as "generic" that serve the majority of applications and upon which more sophisticated interoperable [3] approaches can be built. Additionally lifecycle management has to be supported in order to enable consistent management of such a large infrastructure. In such a multi-stakeholder environment, taking also into consideration the prevalence of IoT in personal and business domains, security, trust and privacy are expected to be challenging issues. These need to be an integral part of design, implementation and deployment of any energy services and of the infrastructure they depend upon.

1.6 Conclusions

Once cooperative infrastructures are in place within a Smart City, a plethora of applications are expected to flourish and offer new innovative services. The latter will enable direct interaction between all Smart City stakeholders for the common benefit. Smart Cities can harness the power of the emerging IoT/CoT enabled Smart Grid and enhance their operation to better suit the needs of their citizens. Informed decisions can now be taken that rely more on actual data and up-to-date analytics, empowering decision-makers with new opportunities for better management and eradication of inefficiencies.

To harness the benefits, there are challenges at technology,business, and social levels that need to be addressed. The future Smart Cities will need to be built on principles of cooperation, openness/interoperability and trust. Extracting and understanding the business relevant information under temporal constraints and being able to effectively integrate them into solutions that utilize the monitor-analyse-decide-manage approach for a multitude of domains is challenging. The high heterogeneity of systems, models, quality of data and associated information, uncertainties as well as complex system-wide interactions, will need to be investigated to identify business opportunities and realize (business) benefits for all stakeholders. Considering also that for instance in Smart Cities much of the “Big Data” will be directly generated by or affect its citizens, data lifecycle management approaches with security and privacy aspects integrated will need to be well-thought.

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