Big Data Over SmartGrid - A Fog Computing Perspective

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***Abstract*—Nowadays, the Cloud is migrating to the edge of the network and the traditional Cloud Computing (CC) paradigm is not enough for the storage of Big Data (BD) produced by Internet of Things (IoT). To meet this requirement, a new platform is needed, namely "*Fog Computing*". Under Fog Computing, most of the functions of data processing are performed out from the Cloud, so that a reliable and efficient communication system is required, in order to get a robust, affordable and secure power supply through SmartGrids (SGs). Computational requirements for SG applications can be met by using the Fog Computing (FC) model. Flexible resources and services shared in network, parallel processing and omnipresent access are some features of FC. In order to apply locally Fog-supported nodes over SGs, we need to introduce SmartLocalGrid (SLG) as a communication paradigm between micro-grids. Even though, the FC model is considered efficient for SLGs and SGs, but it has some constraints, such as security and reliability. In this work, Fog platform, technical support, security, BD analysis and utilization issues are further unveiled according to current FC paradigm. In FC, the Fog Nodes (FNs) can gather BD and transport them to the remote Cloud, in order to perform in-depth data analysis. There are still several issues and challenges to be addressed to achieve a better utilization of this technology. The future of the Cloud should support the idea of the Internet of Everything (IoE), where FC implements BD applications that support, in turn, SG and SLG applications. Finally, Cloud services based on existing SG and SLG prototypes and open research issues are presented.**

Keywords*—*Fog Computing, Cloud Computing, Big Data, SmartLocalGrid, SmartGrid, IoT, IoE

I. Introduction

Fog Computing (FC) is a new paradigm recently promoted by Cisco, that extends Cloud Computing (CC) and services to the edge of the network [1]. It is demonstrated that the applications can be enabled and run directly at the network edge, where billion devices are already connected through the Internet of Things (IoT) [1]. Hence, there is a strict interplay between Cloud and Fog Computing. Specifically, when it comes to data management and analytics, FC reduces service latency, provides location awareness and improves Quality-of-Services (QoS). Moreover, FC supports emerging Internet of Everything (IoE) for streaming and real applications, that include industrial automation, transportation, sensors and actuators networks [2], [3], [4], [5], [6]. FC architecture is emerging, indeed, as a better option than CC for a highly virtualized platform, where the data processing and execution of applications will be no longer centralized in the Cloud, but smartly scattered over *Fog Nodes* (FNs) [7]. So, FC can deal with the increasing number of connected devices and the emerging demand of IoT [5], [8]. Fog is distinguished from Cloud by its proximity to the end-users and allows to reduce the data traffic to the Cloud. Whenever the platform needs to scale either covering more "things", adding more FNs, and supporting heterogeneity; those can be resources-poor devices, such as set-top-boxes, access points, routers, switches, base stations, spanning multiple management domains and end devices [9] [10].

The FC paradigm is well positioned for real time Big Data (BD) analytics. It supports densely distributed data-collection points (e.g., [11]). Hence, it adds a fourth axis to the usually mentioned BD dimensions (i.e., volume, variety, and velocity), and provides advantages in entertainment, advertising, personal computing and other applications. Nowadays, many machines, devices and sensors are being connected to the Internet. Some of these relate to protection and control loops, that require real-time processing (from milliseconds to seconds). The first tier of the Fog is designed for Machine-to-Machine *(M2M)* interactions; through machines interconnection with the Internet, it becomes *"smart"* with the ability to react and make decisions on their own in real-time [12], in order to change the environment or supply chain (see Fig.1) [13]. The second and third tiers deal with visualization and reporting (e.g., Human-to-Machine-Interactions *(HMI)*), as well as systems and processes. The time scales of these interactions over the Fog platform range from seconds to minutes (real-time analytics), up to days (transactional analytics). As a result, Fog must support multiple types of storages, from transient at the lowest tier to semi-permanent at the highest tier.

Consequently, the types of primary communications cover the following tiers (see Fig.1):

- *Machine-to-Machine (M2M):* Data are sent and received from any machine (thing) to another, and connections are sustained by the network capabilities of *IoT* and sensors.
- *People-to-Machine (P2M):* Data are sent and received from people to any machine (thing), and connections

rely on capabilities in *data and analytics*.

- *People-to-People (P2P):* Data are sent and received from people to people, through *collaboration*.

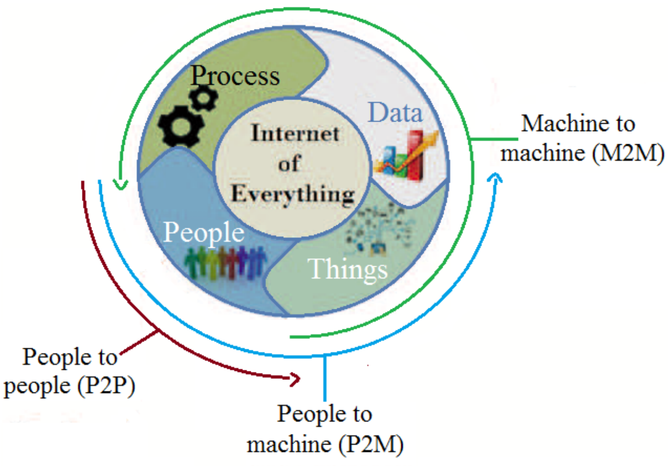

Fig. 1. IoE: brings together people, process, data, and things to make networked connections relevant and valuable.

Bringing together so many machines and devices requires exorbitant customization costs. Introducing SmartLocalGrid (SLG) on Fog Virtualization (FV), e.g., an embedded platform on network, switches, devices, sensors and machines that sit on/between devices and the Cloud, could be a solution [14]. The SmartGrid (SG) and SmartLocalGrid (SLG) make electric utilities smarter (homes, factories, nuclear power plant, thermal power plant, hydraulic power generation, photovoltaic, wind generator, ecological vehicle, cities and offices.) and help to accelerate the transformation of cities into smart cities (smart lighting, smart traffic, wind generation, smart manufacturing, smart homes, structural health, smart neighborhoods, and solar generation).

SLG allows machines to communicate directly to each other without going through the Cloud, and, in turn, it enables real-time decisions and data processing without Cloud support. SLG on FC connects all devices to the Cloud. The result is a "$smart$" network of devices, that are able to make self-decisions, which is called *Fog Computing Platform* (FCP).

After this brief overview on FC, BD, and SGS, in order to extend these concepts and their inter-relationships, the rest of this paper is organized as follows. In Section II, the definitions of the Fog platform (FP) and architecture are reviewed. In Section III, we present SmartGrid/SmartLocalGrid and their characteristics. Section IV focuses on the emerging FC-BD interplay. Section V presents relevant published works and discuses their inter-play. Section VI lists some challenges and future trends. Finally, Section VII concludes this position paper.

II. Fog Computing Architecture

In this section, we introduce the platform of Fog and its architecture; then, we go to introduce Fog characterization and the start-of-the-art software architecture supporting Fog technology.

A. *The Fog Platform*

According to Cisco, by 2020[1], 50 billion of devices will be connected to the Internet. Therefore, sufficient bandwidth requirements and latency would be critical issues. On the other hand, the magnitude of the resulting traffic will be a stability problem. Also, there are still some questions: what happens when this huge amount of traffic starts to transfer through the network? how can we basically put some (possible, virtual) checks and balances on all the data, before sending it towards the Cloud? To response these questions, we need to exploit available devices and decide faster, instead of sending everything to the Cloud without supervising. In order to control and manage data as well as providing secure environment, we need to establish/construct a robust platform between Cloud and IoT devices. This platform retains the benefits of Cloud (such as, agility, flexibility and distributed computing), while allowing communication of the data over the IoT devices much easier than Cloud, which is called *Fog*.

FC is the key enabler of the Internet of Everything (IoE), where Fog development phases are summarized to give an overview of IoE and IoT. The study of the science category and supporting technologies will bring an array of new cases in every life field, talent, education, and industry are significant aspects to help build IoE. The Fog vision was conceived to address applications and services that do not well fit with the Cloud paradigm [15]. They include:

- *Edge locations, awareness*, and *low latency*: FC supports endpoints by rich services at the edge of the network, including applications that require very low and predictable latency (e.g., games, video conferences).
- *Geographical distribution*: FC contrasts against the more centralized Cloud, by creating an edge network which is widely geographically distributed. Therefore, BD analytics can be done faster and with better results. Fog plays an important role in delivering high-quality streaming to connected vehicles moving through proxies and access points positioned next to the users.
- *Heterogeneity* and *large-scale*: Fog-supported sensor networks will be deployed in a wide variety of environments to monitor the SG. They require distributed computing and storage resources.

In some user's cases, FC fills the inadequacies of the Cloud-based model, which has serious challenges with latency, network bandwidth, geographic focus, reliability and security.

FC complements and interplays with the Cloud to support applications that require low/predictable latency, rapid mobility, and are widely geographically distributed. Fog provides $intelligence$ closer to the Data source. In other words, in Fig.2, FNs (a big star closer to the Cloud and a medium one closer to the edges) are the medium devices which help heterogeneous devices to collaborate with each others, as well as process and transfer data faster with less overload. In this figure, local processing are presented inside the arc and networking processing are presented over the arc.

The Content Delivery Network (CDN) [16] represents the most mature catch network that is extensively pursued in

[1] http://www.cisco.com/

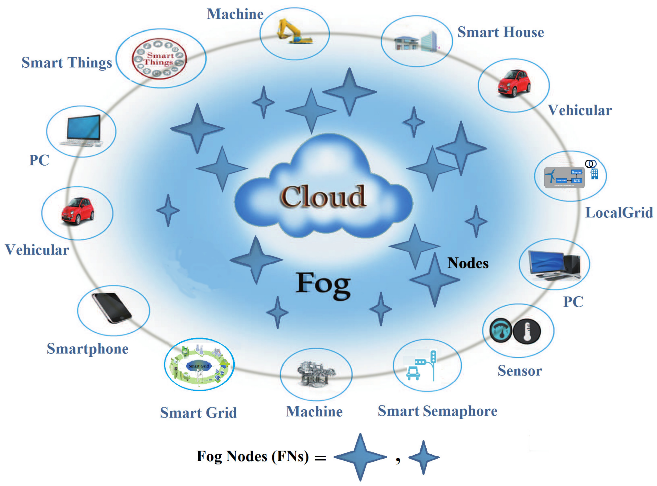

Fig. 2. Fog platform

academic and industry. CDN deploys cache servers at the edge of Internet, in order to reduce download delays. CDN serves traditional desktop Internet users, which have much broader interests and blur service demands that are more difficult to predict than those of mobile users. FC has much clear users' target for specific service demand. This is the key for FSs to explore specific service demand to fully utilize their storages and computing resources, in order to provide the most desirable services to mobile users. FSs can be connected to the Cloud and accordingly utilize the extensive computing power and BD tools (such as, Hadoop, Cloudera, MongDB, Talend, Pentaho, Keel, etc.) for rich applications, rather than content distribution, such as IoT, vehicular communications and SG applications [13]. Furthermore, FC is able to incorporate the proactive caching framework as described in [17].

III. SmartGrid and SmartLocalGrid

FC is essential in the middle of the smart center because it helps the Industry and the things. Specifically, FC considers numerous different market protocols as energy, agriculture, SmartGrid (SG), SmartLocalGrid (SLG), SmartCity (SC), SmartHome (SH), SmartTransportation (ST), healthcare, intelligent buildings, defense, enhance safety and security, and predictive maintenance.

For the provisioning of such SG Data-as-a-Service (DaaS), a platform-centric FC approach, which has proven to accommodate Internet-scale data and computing intensive applications in a multi-tenant setting [18], [19], [20]. In the research community, there are current efforts to classify and deliver appropriate definition of FC [21], [22]. In this paper, we are providing a conceptual view on FC as a platform for SG/SLG data management. The emphasis is on the specific characteristics of FC, which result in an Internet-scale platform and may facilitate the data-intensive needs of the SG user's cases.

A. SmartGrid

SmartGrid (SG) is a combination of electrical network and communication infrastructure [23]. It consists of a power network with $intelligent$ energy load balancing that may run on edge devices, such as smart meters, in secure, reliable, and scalable ways [24]. Based on demand of energy, it finds availability and low cost scheduling. FC is envisaged to play key roles of motivation in the design of the future SG [13]. Using the Fog Infrastructure, a customer can gain access to his/her applications anytime, through a device connected to the edge of the network. Also, FI supports real-time two-way communication between utilities and consumers. Additionally, energy demands from users change dynamically in different time-periods (on-peak, off-peak, and mid-peak), which in turn, requires dynamic availability of communication resources, such as bandwidth, processing units, and storage devices. For this reason, it exists the need to integrate into a common platform with the SG, which is able to support the FI. A SG allows various renewable energy sources, like solar energy, wind power, hydroelectric, radiant energy, geothermal energy, biomass. Multiple devices are implemented as home appliances, smart meters, micro-grid, substations, sensor nodes, and communication-network devices [25]. Information management is an important aspect in the SG architecture [26]. In a big environment, millions of smart meters are deployed in the distribution sites and generate massive data for real-time communication [27]. At the edge process, the data collected by Fog collectors generated by grid sensor, devices and issue control commands to the actuators that also filter the data to be consumed locally, and send the rest to the higher tiers, for virtualization and reporting for real-time [13]. Fog supports momentary storage at the lowest tier to semi-permanent storage at the highest tier.

Micro-grids recently emerged as a promising technology to integrate with the main power grid and alternate distributed power generators, as wind farms, solar cells, micro turbines, wasted to energy, and etc. It is the integration of low-voltage electricity system with self-generating facilities [28]. Additionally, they can control and distribute electricity to the end-users [29]. The micro-grid is able to control the power flow autonomously, due to the fluctuation in renewable energy sources, decentralized control techniques for microgrids [30], [31], comprised of distributed generators, energy storage, and loads which may connect to the power grid or operate autonomously [32], [33].

B. SmartLocalGrid

SmartLocalGrid (SLG) is a combination of micro-grids network and communication infrastructure. SLG grows over time and it provides a simple integration, information and solution that improves the effectiveness of power micro-grids at the local level [34]. SLG provides a next-generation approach to settle one of the great today's challenges by increasing the reliability of electrical micro-grids to satisfy the 21st century growing needs.

Many machines and a very large number of devices are connected to the Internet, in order to transmit useful measurement information and control instructions via distributed sensor networks. They become $smart$ with the ability to make decisions and react. Sensors, devices and machines (things) are wirelessly connected through network switches and devices [35], [36].

Since, these machines and sensors record data in real-time every second or minute, the amount of data could be too much to handle for the network, multiplied by hundreds of machines across multiple plans, all together mean an exorbitant customization cost, and the latency can be a big issue when real-time decisions need to be made. The introduction of SLG on Fog Platform (FP) aims to eliminate the bandwidth and latency issues. SLG ensures communication between all devices (see Fig.2). On FP, the customization and service cost kept the minimum. SLG allows $M2M$ direct connections without going through the Cloud and enabling real-time decision without transmitting an amount of data to the Cloud [37]. SLG connects all devices to the Cloud with open communications standards, becoming a smart network and the devices are able to make decisions for themselves and react in real-time to changing environments. Moreover, all SLG devices can communicate with the Cloud through open communication standards. Applications running on SLG's platform can utilize the interplay between the Fog and Cloud to solve more complex problems [38].

IV. Fog Computing and Big Data

FC allows to deliver the right data at the right time to people on any device. The model for data analytics involves a centralized data warehouse manual data manipulation and investigation, with the vast amount of data of IoE pouring. It is difficult to find and act on the right data if the data is houses in centralized data warehouses. Thus, they require high bandwidth to get information from that point, in order to analyze the vast amount of data around which result in lower reliability and higher network latency. FC promises to unleash executable data in real-time at the end of the network by supporting mobility, location awareness and geographical distribution. FC connects sensors to CC resources to enable rapid and executable decisions to be made based on BD pouring from the IoE. FP filters BD and pushes relevant data to the Cloud, meaning that it supports real-time, executable analytics and enables processes, wherever people are (located). Emerging data virtualization and FC technologies are helping industry, education, and in general with things overcome the challenges of centralized data processing. Data Virtualization Software (DVS) makes it seamless to manipulate and view data, without matter where it resides. DVS and FC bring intelligence and analytical capabilities to the data, resulting into the ability to act on vast amount of heterogeneous data [39].

Fog Data Services (FDS) is an IoT software product that runs in the network and aim to transform raw data from sensors and endpoints to actionable information [40]. While critical time-sensitive data is stored and analyzed at the network edge, less time-sensitive data can go to the Cloud for long-term storage and historical analysis. FDS acts on data at the source and the edge of the network. So, their operations can use data immediately, and reduces the stress of the network, Cloud resources and infrastructure. Moreover, FDS deploys IOx virtual machines running on devices in the Fog.

FDS builds scalable IoT solutions with consistent APIs across a variety of ruggedized network devices and endpoints.

A. IoT data

IoT on Fog architecture is the cornerstone of the future IoT. It is a fundamental issue that provides a supporting platform for addressing other issues in IoT. IoT is an important source of BD. In smart cities, IoT-induced BD may come from industry, agriculture, traffic, transportation, medical care, public departments, and family, etc. As it was mentioned above, this network architecture may be divided into three layers, namely, the perception layer, the network layer and the application layer (see Fig. 3). The perception layer is responsible for data acquisition and consists of various sensors, sensor gateways and actuators responsible for collecting information, controlling and identifying things. The network layer includes a variety of networks and it is responsible for transmission and processing information. Finally, the application layer is the interface between IoT services and users.

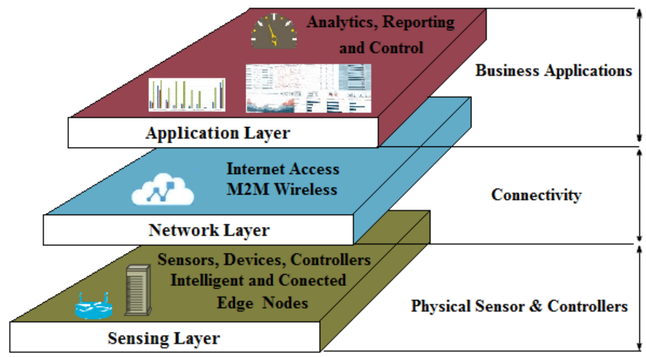

Fig. 3. IoT model

Data flows generated by IoT have the following features:

- *Large-scale:* in IoT, a number of data-acquisition equipments are distributed, which may acquire simple numeric data, as location, or complex multimedia data, as surveillance video, for meeting demand of analysis and processing.
- *Heterogeneity:* due to the variety of data acquisition devices, the acquired data are different and such data feature heterogeneity.

In IoT, any data acquisition device is placed at a specific geographic location and every piece of data has a timestamp. Moreover, space-time correlation is an important property of data from IoT. During data analysis and processing, time and space are also important dimensions for statistical analysis. A great level of noise can occur during the acquisition and transmission of data in IoT [41]. Among data sets acquired by devices, only a small fraction of abnormal data is valuable during the acquisition of traffic video, the few video frames that capture the violation of traffic regulations and traffic accidents are more valuable than those that capture the normal flow of traffic [42]. While adding FC to an IoT network, would seem to add complexity that complexity is sometimes necessary [5].

V. Recent Works

In order to allow a cleaver comparison, we classify Fog-based SG issues which are exploited to manage BD into three classes: energy management, information management and security (see Table. I).

TABLE I. CLASSIFICATION OF THE APPLICATION TECHNOLOGIES IN FC/SG/BD.

Technology	Applications	Fog Computing Applications	SmartGrid Features	Big Data
Energy Management	• Micro-grid management [43],[44], • Dynamic demand response operated within the micro-grid [45], • Real-time monitoring on application for SG [46].	• Data-metric communication with the implementation of private Fog for small size network, • Fog Application dynamically increase bandwidth capacity to avoid congestion, • Micro-grid to micro-grid interaction through Fog, • Define demand response model in the into the internal micro-grid operation.	• Micro-grid Management • Dynamic Pricing	The quality-of-service (QoS) support in the network is extremely important for real-time Big Data applications for SG. In these applications, all current distributed should be application events transfer in real-time to where they can be responses.
Information Management	• Smart meter data streams in Cloud [47],[45],[48], • Dynamic data center operation [49], [50].	• Guaranteed work-flow latency and processing rates with the help of Fog data optimization, • Dynamic pricing model in SmartGrid architecture according to load on Fog Data Service (FDS), • Adequate data transfer framework from users to Fog and, vice-versa.	• Cost optimization • Data Storge and Processing	Big Data can processed on the Fog using both Big Data Platform-as-a-Service (PaaS) and Infrastructure-as-a-Service (IaaS). This will relieve the applications of securing dedicated platforms, which is usually very costly and allow them to use well tested highly reliable offered by the Fog Service Providers (FSP).
Security	• Security and protection system for electric power information [51],[52], [53], • Privacy preserving over encrypted metering data for SmartGrid [54], [55], [56], [53].	• Fog as "Software-as-a-Service" (SaaS) for data privacy issues in large scale deployment of SmartGrid (SG), • Define security mechanism for SmartGrid while using public Fog Computing applications, • Effective and efficient security and privacy policies to support increasing data from smart meters.	• Data Security and Privacy • Threat Detection • Cyber Security	The most data collected and processed in SG applications contain some form of sensitive or private information, it is important to ensure that all technology and applications components include and maintain acceptable levels of security and privacy mechanisms.

VI. OPEN ISSUES

1) Education: Academic research has developed a wide variety of techniques and technologies to capture, select, analyze and visualize BD. Therefore, their technologies can be simplified into an integrated system, that includes network infrastructure service, education information services, learning services. Where the lead benefit is get new knowledge, facilitate higher-order thinking skills. Each student generates a unique data track where the data could be inserted, processed and analyzed [57]. Nowadays, more and more classrooms are becoming *open* through voice, video, and text-based collaboration, and recently teachers have a wide range of multi-modal resources to enhance teaching. In the computer science field, the challenge is in developing different forms of innovative education that adjust large numbers of students around the world, engage students with several interests, and carry out an new curriculum that show the fundamental changes in computing technology [58].

2) Transportation, Mobility and Renewable Energy: Due to the growing penetration of renewable energy sources and expected widespread adoption of electric vehicles, SGs need to implement efficient monitoring and control technologies to improve its operational efficiency. The Electric Vehicles (EVs) may also act as storage devices and feed power back to the grid to smooth out the natural intermittent of renewable energy sources which strengthens the need for a bidirectional energy flow in the grid [59].

VII. CONCLUSIONS

In this position paper, we provide an overview of existing works about the integration of Fog Computing in the future SmartGrid/SmartLocalGrid architectures which support BD. Using the BD SmartGrid/SmartLocalGrid applications atop FC is one of the more useful techniques to win the challenges related to traditional power grid management, despite the existence of some technical problems inherent FC. SmartGrid, Fog Computing and Big Data are three modern and important paradigms: we stressed the general benefits of using BD to design and support SmartGrid/SmartLocalGrid applications on Fog Computing Platforms. We suggested a list of general requirements for BD SmartGrid/SmartLocalGrid applications on FCP, being these requirements necessary to design and implement effective and efficient BD applications. Moreover, we listed the technologies which are implemented to support Fog-based BD SG/SLG systems. Finally, we discussed some of the main open issues that need to be further investigated and addressed to reach a more comprensive view of SG/SLG.

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