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Review

State-of-the-art, challenges, and open issues in the integration of Internet of things and cloud computing

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ABSTRACT

The Internet of Things (IoT) is a paradigm based on the Internet that comprises many interconnected technologies like RFID (Radio Frequency IDentification) and WSAN (Wireless Sensor and Actor Networks) in order to exchange information. The current needs for better control, monitoring and management in many areas, and the ongoing research in this field, have originated the appearance and creation of multiple systems like smart-home, smart-city and smart-grid. However, the limitations of associated devices in the IoT in terms of storage, network and computing, and the requirements of complex analysis, scalability, and data access, require a technology like Cloud Computing to supplement this field. Moreover, the IoT can generate large amounts of varied data and quickly when there are millions of things feeding data to Cloud Computing. The latter is a clear example of Big Data, that Cloud Computing needs to take into account. This paper presents a survey of integration components: Cloud platforms, Cloud infrastructures and IoT Middleware. In addition, some integration proposals and data analytics techniques are surveyed as well as different challenges and open research issues are pointed out.

Contents

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1. Introduction

The Internet of Things was probably introduced by Ashton (2009) in 1999. The IoT can be defined as a set of interconnected things (humans, tags, sensors, and so on) over the Internet, which have the ability to measure, communicate and act all over the world. The key idea of the IoT is to obtain information about our environment to understand and control and act on it. The IoT can help us in our daily life, e.g. Zaslavsky et al. (2012), where a smart home scenario adapts to the everyday user improving their quality of life and home consumption through a set of home sensors and data information city. Furthermore, the IoT is also suitable in Ambient-Assisted Living, Smart Unit, Monitoring, Tracking, Control systems, Safer Mining Production and so on (Botta et al., 2014; Sindhanaiselvan and Mekala, 2014; Singh et al., 2014; Gubbi et al., 2013; Da Xu et al., 2014). However, the IoT usually coincides with sensors with low power, low memory and battery and network limitations, so there is a need of computing, storage and access and analysis of IoT data (Zaslavsky et al., 2012). Furthermore, there are large amounts of heterogeneity data and devices (Compton et al., 2012) which will grow (Zaslavsky et al., 2012), so a platform that can handle all of this is necessary.

Cloud Computing enables a convenient, on demand and scalable networks access to a pool of configurable computing resources (Zaslavsky et al., 2012). Cloud Computing has virtually unlimited capabilities in terms of storage and processing power (Botta et al., 2014), which are the main drawbacks of IoT. Therefore, by Cloud Computing, IoT can be abstracted of its limitations, heterogeneity, connectivity, identification and security of devices involved (Zorzi et al., 2010). There are different types of categories in Cloud Computing: IaaS (Infrastructure as a Service) which is the lowest layer in a Cloud Infrastructure and offers a poll of Virtual Machines for computing and storage, PaaS (Platform as a Service) is the middle layer which allows deploying applications, and SaaS (Software as a Service) the top layer, that offers accessible user applications like IBM Bluemix, OPENSHIFT, Google App Engine, HEROKU and Microsoft Azure.

The Cloud Computing and IoT integration, known as Cloud of Things (Aazam et al., 2014), solves such problems as IoT's limitations, data access, computing, data analysis, and can create new opportunities, like Smart Things, Things as a Service and SenaaS (Sensor as a Service) (Barbaran et al., 2014; Madria et al., 2014). Moreover, offering a PaaS, users can build applications which use and handle System's Things; even external applications can acquire semantic standard data through Linked Data (Le-Phuoc et al., 2012). The latter takes advantage of the data acquired and saves storage space. Due to the integration benefits and the proliferation of Cloud Computing in recent years, there are several projects and strong research efforts in this field. In the last few years, multiple platforms, protocols, and systems have emerged to tackle the challenges of Cloud Computing and IoT constrained devices.

This paper aims to present the state of the art of different levels of integration components, analyzing different existing proposals in this field and pointing out some challenges and open research issues. Previous research has surveyed Cloud Computing and IoT integration. A survey of Cloud Computing and Wireless Sensor Networks (WSN) overview some applications with both, known as Sensor-Cloud which is presented in Sindhanaiselvan and Mekala (2014). Botta et al. (2014) survey the need for integration, showing some applications thanks to this paradigm and mentioning some open issues and future directions. IoT challenges, visions and applications and the importance of cloud computing and semantics in this field is surveyed in Singh et al. (2014). The term the Cloud of Things and some key integration issues have been introduced by Aazam et al. (2014). Also, Gubbi et al. (2013) present the IoT as an emerging technology, show applications, tends, a cloud centric IoT approach, and mentioned Cloud Computing as an open challenge in the IoT. Our approach does not focus on scenarios where the IoT and Cloud Computing are suitable or limitations or needs as other work has. However, our approach attempts to offer a practical vision to integrate current components of Cloud Computing and the IoT.

Also we know the current limitations on IoT devices, especially on embedded devices, so although we have surveyed different cloud technologies to improve these, the software for embedded devices is a key challenge to achieve the desired integration. In addition to the limitations of the devices, IoT also requires applications in critical and real-time systems where low-latency and low-bandwidth-usage are key requirements. We have taken into account the latter and we have tried to survey an integration which addresses these requirements.

The rest of the paper is organized as follows. In Section 2 integration components are surveyed. Section 3 analyzes current proposals in multiple areas for this field. Section 4 shows data analytics techniques for optimizing such integration. In Section 5 some case studies are analyzed for discussing about the elements surveyed. Section 6 points out challenges and open research issues. Finally, conclusions are drawn in Section 7.

2. Integration components

We have classified the integration components into three categories taking into account the need for a seamless integration. On the one hand, we have surveyed multidisciplinary Cloud Platforms to satisfy IoT limitations and to offer new business opportunities and more scalability. For the deployment, management and monitoring of Cloud Platforms, we have surveyed different Cloud Infrastructures. And lastly, we have surveyed several IoT middleware to abstract the underlying heterogeneous IoT devices.

Cloud Computing and IoT integration provides new storage, processing, scalability and networking capabilities which are so far limited in the IoT due to its characteristics. Furthermore, new opportunities like complex analysis, data mining and real-time processing will be present on IoT, hitherto unthinkable in this field. Finally, through the IoT Middleware, the IoT devices will have a lightweight and interoperable mechanism for the communication among themselves and with the Cloud systems deployed. Fig. 1 shows the integration components surveyed in this paper.

2.1. Cloud platforms

Recently and in the future, the number of users and data from IoT will grow significantly as the number of connected devices increases (Zaslavsky et al., 2012). For a long time, DBMS (Database Management Systems) have been used to store and access data in a great number of applications. Nevertheless, the growth in users and data means that a large number of DBMS are unsuitable. Hence, a platform which can tackle these needs is required in order to offer high scalability, storage and even processing. In this subsection, we summarize different platforms for storing, processing and accessing large amounts of heterogeneity data, which has recently become known as Big Data (Zaslavsky et al., 2012).

2.1.1. Batch processing

Processing and analyzing large amounts of data is one of the requirements addressed in the integration proposal. Batch processing components are responsible for the execution of a series of jobs without manual intervention, allowing a greater distribution of these and high throughput.

An open source framework to manage large amounts data is approached by Shvachko et al. (2010). Hadoop is composed by