INTEGRATION OF CLOUD COMPUTING WITH IOT

1 INTRODUCTION

It is important to explore the common features of the technologies involved in the field of computing. Indeed, this is certainly the case with Cloud Computing and the Internet of Things (IoT) – two paradigms that share many common features. Cloud computing has altered the way in which technologies can be accessed, managed, and delivered. It is widely agreed that Cloud computing can be used for utility services in the future. Cloud computing has been involved in and encompassed various technologies such as grid, utility computing virtualization, networking, and software services. Cloud computing provides services that make it possible to share computing resources across the Internet. As such, it is not surprising that the origins of Cloud technologies lie in grid, utility computing virtualization, networking and software services, as well as distributed computing, and parallel computing.

On the other hand, the IoT can be considered both a dynamic and global networked infrastructure that manages self-configuring objects in a highly intelligent way. The IoT normally includes a number of objects with limited storage and computing capacity. It could well be said that Cloud computing and the IoT will be the future of the Internet and next-generation technologies. However, Cloud services are dependent on service providers which are extremely interoperable, while IoT technologies are based on diversity rather than interoperability.

2 BASIC CONCEPTS

A. CLOUD COMPUTING

The National Institute of Standards and Technology (NIST) has defined Cloud computing as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction". Cloud computing comprises four types of deployment models, three different service models, and five essential characteristics.

Cloud computing deployment models are most commonly classified as belonging to the PUBLIC CLOUD, where resources are made available to consumers over the Internet. Public Clouds are generally owned by a profitable organisation (e.g. Amazon). Conversely, the infrastructure of a PRIVATE CLOUD is commonly provided by a single organisation to serve the particular purposes of its users(Microsoft Private Cloud). HYBRID CLOUDS are a mixture of private and public Clouds. This choice is provided for consumers as it makes it possible to overcome some of the limitations of each model. In contrast, a COMMUNITY CLOUD is a Cloud infrastructure which is delivered to a group of users by a number of organizations that share the same need.

Services in Cloud computing are provided at three different levels, namely: the Software as a Service (SaaS) model, where software is delivered through the Internet to users (e.g. GoogleApps); the Platform as a Service (PaaS) model, which offers a higher level of an integrated environment that can build, test, and deploy specific software (e.g. Microsoft Azure); and finally, with the Infrastructure as a Service (IaaS) model, infrastructure such as storage, hardware and servers are delivered as a service (e.g. Amazon Web Services).

B. INTERNET OF THINGS

All things in the IoT (smart devices, sensors, etc.) have their own identity. They are combined to form the communication network and will become actively participating objects. All IoT devices can be monitored, tracked and counted, which significantly decreases waste, loss, and cost. According to the ITU (2012), the IoT is "a global infrastructure for the Information Society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies". The IoT introduces a variety of opportunities and applications. However, it faces many challenges which could potentially hinder its successful implementation, such as data storage, heterogeneous resource-constrainted, scalability, Things, variable geospatial deployment, and energy efficiency.

C. CLOUD-BASED INTERNET OF THINGS

The IoT and Cloud computing are both rapidly developing services, and have their own unique characteristics. On the one hand, the IoT approach is based on smart devices which intercommunicate in a global network and dynamic infrastructure. On the other hand, Cloud computing comprises a massive network with unlimited storage capabilities and computation power. Furthermore, it provides a flexible, robust environment that allows for dynamic data integration from various data sources. Cloud computing has partially resolved most of the IoT issues. Indeed, the IoT and Cloud are two comparatively challenging technologies and are being combined in order to change the current and future environment of internetworking services. The Cloud-based Internet of Things is a platform which allows for the smart usage of applications, information, and infrastructure in a cost-effective way. While the IoT and Cloud computing are different from each other, their features are almost complementary.

TABLE 1. COMPARISON OF THE IOT WITH CLOUD COMPUTING

Items	IoT	Cloud Computing
Characteristics	IoT is pervasive (things are everywhere). These are real world objects.	Cloud is ubiquitous (resources are available from everywhere). These are virtual resources.
Processing capabilities	Limited computational capabilities.	Virtually unlimited computational capabilities.
Storage capabilities	Limited storage or no storage capabilities.	Unlimited storage capabilities.
Connectivity	It uses the Internet as a point of convergence.	It uses the Internet for service delivery.
Big data	It is a source of big data.	It is a means by which to manage big data.

3 BENEFITS OF INTEGRATING IOT WITH CLOUD

1. COMMUNICATION
   Ubiquitous applications can be transmitted through the IoT, whilst automation can be utilised to facilitate low-cost data distribution and collection. The Cloud is an effective and economical solution which can be used to connect, manage, and track anything by using built-in apps and customised portals. It is worth declaring that, although the Cloud can greatly develop and facilitate the IoT interconnection, it still has weaknesses in certain areas. Thus, practical restrictions can appear when an enormous amount of data needs to be transferred .

2. STORAGE
   As the IoT can be used on billions of devices, it comprises a huge number of information sources, which generate an enormous amount of semi-structured or non-structured data. This is known as Big Data, and has three characteristics: variety (e.g. data types), velocity (e.g. data generation frequency), and volume (e.g. data size). The Cloud is considered to be one of the most cost-effective and suitable solutions when it comes to dealing with the enormous amount of data created by the IoT. Moreover, it produces new chances for data integration, aggregation, and sharing with third parties.

3. PROCESSING CAPABILITIES
   IoT devices are characterised by limited processing capabilities which prevent on-site and complex data processing. Instead, gathered data is transferred to nodes that have high capabilities. However, achieving scalability remains a challenge without an appropriate underlying infrastructure. Offering a solution, the Cloud provides unlimited virtual processing capabilities and an on-demand usage model. Predictive algorithms and data-driven decisions making can be integrated into the IoT in order to increase revenue and reduce risks at a lower cost.

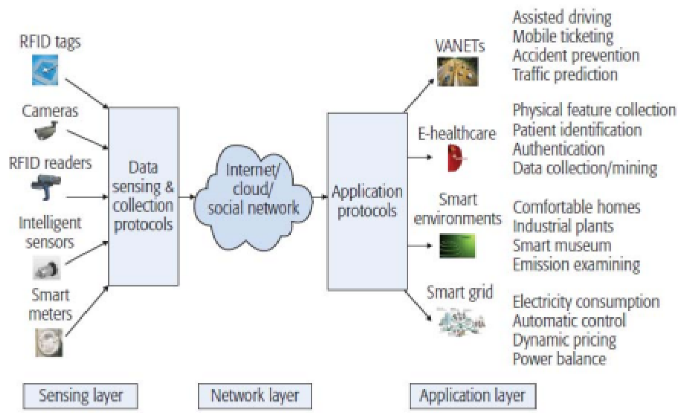
4. SCOPE
   The Cloud-based IoT approach provides new applications and services based on the expansion of the Cloud through the IoT objects, which in turn allows the Cloud to work with a number of new real world scenarios, and leads to the emergence of new services.

5. NEW ABILITIES
   The IoT is characterised by the heterogeneity of its devices, protocols, and technologies. Hence, reliability, scalability, interoperability, security, availability and efficiency can be very hard to achieve. Integrating IoT into the Cloud resolves most of these issues. It provides other features such as easeof-use and ease-of-access, with low deployment costs.

6. NEW MODELS
   • SaaS (Sensing as a Service), which allows access to sensor data. • EaaS (Ethernet as a Service), the main role of which is to provide ubiquitous connectivity to control remote devices. • SAaaS (Sensing and Actuation as a Service), which provides control logics automatically. • IPMaaS (Identity and Policy Management as a Service), which provides access to policy and identitymanagement. • DBaaS (Database as a Service), which provides ubiquitous database management. • SEaaS (Sensor Event as a Service), which dispatches messaging services that are generated by sensor events. • SenaaS (Sensor as a Service), which provides management for remote sensors. • DaaS (Data as a Service), which provides ubiquitous access to any type of data.

4 CLOUD-BASED IOT ARCHITECTURE

According to a number of previous studies, the well-known IoT architecture is typically divided into three different layers: application, sensing and network layer. Most assume that the network layer is the Cloud layer, which realises the Cloudbased IoT architecture. The sensing layer is used to



identify objects and gather data, which is collected from the surrounding environment. In contrast, the main objective of the network layer is to transfer the collected data to the Internet/Cloud. Finally, the application layer provides the interface to different services.

5 CLOUD-BASED IOT APPLICATIONS

1. HEALTHCARE: Cloud-based IoT develop and improve healthcare services and keep the field innovative (e.g. intelligent drug/medicine control, hospital management).

2. SMART CITIES: IoT technologies will lead to the generation of services that can communicate with the surrounding environments (e.g. Smart streetlights, Bigbelly, ShotSpotte).

3. VIDEO SURVEILLANCE: Intelligent video surveillance will make it possible to manage, store, process video content and extract information from video sensors easily and efficiently.(e.g. Wireless CCTV Cameras).

4. AUTOMOTIVE AND SMART MOBILITY: The integration of Cloud computing into The Global Positioning System (GPS) represents a opportunity to solve many of the existing challenges (e.g. traffic state prediction notification, remote vehicles).

5. SMART ENERGY AND SMART GRID: Cloud computing and the IoT can work together effectively to provide consumers with smart management of energy consumption (e.g. smart meters, smart appliances, renewable energy resources).

6. SMART LOGISTICS: It allows for, and eases, the automated management of goods flow between producers and consumers, while simultaneously enabling the tracking of goods in transit (e.g. logistics industry, tracking shipments).

6 CHALLENGES FACING CLOUD-BASED IOT INTEGRATION

1. SECURITY AND PRIVACY
   Important issues which has not yet been resolved is how to provide appropriate authorisation rules and policies while ensuring that only authorised users have access to the sensitive data.Sensitive information leakage can occur due to the multi-tenancy. Moreover, public key cryptography cannot be applied to all layers because of the processing power constraints imposed by IoT objects.

2. HETEROGENEITY
   Cloud platforms suffer from heterogeneity issues; for instance, Cloud services generally come with proprietary interfaces, thus allowing for resource integration based on specific providers. In addition, the heterogeneity challenge can be exacerbated when end-users adopt multi-Cloud approaches, and thus services will depend on multiple providers to improve application performance and resilience.

3. BIG DATA
   Finding a perfect data management solution which will allow the Cloud to manage massive amounts of data is still a big issue. Furthermore, data integrity is a vital element, not only because of its effect on the service's quality, but also because of security and privacy issues, the majority of which relate to outsourced data.

4. PERFORMANCE
   The key issue is obtaining adequate network performance in order to transfer data to Cloud environments. In a number of scenarios, services and data provision should be achieved with high reactivity. This is because timeliness might be affected by unpredictable matters and real-time applications are very sensitive to performance efficiency.

5. LEGAL ASPECTS
   Legal aspects have been very significant in recent research concerning certain applications. For instance, service providers must adapt to various international regulations. On the other hand, users should give donations in order to contribute to data collection.

6. MONITORING
   Monitoring is a primary action in Cloud Computing when it comes to performance, managing resources, capacity planning, security, SLAs, and for troubleshooting. As a result, the Cloudbased IoT approach inherits the same monitoring demands from the Cloud, although there are still some related challenges that are impacted by velocity, volume, and variety characteristics of the IoT.

7. LARGE SCALE
   The large scale of the systems raises many new issues that are difficult to overcome. For instance, achieving computational capability and storage capacity requirements is becoming difficult. Moreover, the monitoring process has made the distribution of the IoT devices more difficult, as IoT devices have to face connectivity issues and latency dynamics.

7 OPEN ISSUES AND RESEARCH DIRECTIONS

1. STANDARDISATION
   Many studies have highlighted the issues of lack of standards, which is considered critical in relation to the Cloudbased IoT paradigm. Architectures, standard protocols, and APIs are required to allow for interconnection between heterogeneous smart things and the generation of new services, which make up the Cloudbased IoT paradigm.

2. FOG COMPUTING
   Fog can essentially be considered an extension of Cloud Computing which acts as an intermediate between the edge of the network and the Cloud; indeed, it works with latency-sensitive applications that require other nodes to satisfy their delay requirements. Although storage, computing, and networking are the main resources of both Fog and the Cloud, the Fog has certain features, such as location awareness and edge location, that provide geographical distribution, and low latency; moreover, there are a large nodes; this is in contrast with the Cloud, which is supported for real-time interaction and mobility.

3. CLOUD CAPABILITIES
   As in any networked environment, security is considered to be one of the main issues of the Cloud-based IoT paradigm. There are more chances of attacks on both the IoT and the Cloud side. In the IoT context, data integrity, confidentiality and authenticity can be guaranteed by encryption. However, insider attacks cannot be resolved and it is also hard to use the IoT on devices with limited capabilities.

4. SLA ENFORCEMENT
   Ensuring a specific Quality of Service (QoS) level regarding Cloud resources by depending on a single provider raises many issues. Thus, multiple Cloud providers may be required to avoid SLA violations. However, dynamically choosing the most appropriate mixture of Cloud providers still represents an open issue due to time, costs, and heterogeneity of QoS management support .

5. BIG DATA
   Big Data is considered a critical open issue, and one in need of more research. The Cloud-based IoT approach involves the management and processing of huge amounts of data stemming from various locations and from heterogeneous sources; indeed, in the Cloud-based IoT, many applications need complicated tasks to be performed in real-time.

6. ENERGY EFFICIENCY
   Recent Cloud-based IoT applications quickly consumes the node energy. Several directions have been suggested to overcome this issue, such as compression technologies, efficient data transmission; and data caching techniques for reusing collected data with time-insensitive application.

7. SECURITY AND PRIVACY
   Adapting to different threats from hackers is an issue. Moreover, another problem is providing the appropriate authorisation rules and policies while ensuring that only authorised users have access to sensitive data; this is crucial for preserving users' privacy, specifically when data integrity must be guaranteed.

8 CONCLUSION

The IoT is becoming an increasingly ubiquitous computing service which requires huge volumes of data storage and processing capabilities. The IoT has limited capabilities in terms of processing power and storage, while there also exist consequential issues such as security, privacy, performance, and reliability; As such, the integration of the Cloud into the IoT is very beneficial in terms of overcoming these challenges. In this paper, we presented the need for the creation of the Cloud-based IoT approach. Discussion also focused on the Cloud-based IoT architecture, different applications scenarios, challenges facing the successful integration, and open research directions. In future work, a number of case studies will be carried out to test the effectiveness of the Cloud-based IoT approach in healthcare applications.

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