

Cloud of Things: A State-of-the-art Review on Integration of Internet of Things with Cloud Computing

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ABSTRACT

Cloud Computing and Internet of Things (IoT) are two very diverse technologies of the Future Internet. Both technologies have been widely studied and applied in various fields, as they are on-demand in use, provide efficient sharing of resources and comprises billions of objects for intelligent communication. In modern world a new concept is introduced with the integration of Cloud computing and Internet of Things i.e. Cloud of Things. It covers a wide variety of applications and having potential to grow on large scale in future. This paper focuses on a state-of-the-art review on the Cloud of Things paradigm. In recent years, various literature works have been written on its overview, issues, research challenges and applications. Therefore, this study provides a brief analysis of this new Cloud of Things concept and classified this study into a brief overview, features, research concern issues & their potential solutions, major challenges to be investigated by the research communities, applications and future work.

General Terms

Computing, Networking.

Keywords

Cloud Computing, Internet of Things (IoT), Integration, Cloud of Things and Networking etc

1. INTRODUCTION

In recent years, with the growth of competitive market and increasing demands of customers have led to the quick development and use of networking, advanced computing technologies, virtualization, cloud computing [1], Internet of Things (IoT) [2], service-oriented technologies (SOTs) [3], Green IT [4] and cyber-socialization. In such environment of high-performance computing technologies, Grid and parallel computing enables the processors to solve large-scale problems; virtualization enables the technology to hide the geographical location and characteristics of resources from users; the IoT technology realizes the intelligent self configuring nodes (things) to be interconnect the physical world to information world for effective communication; SOTs provide web services, ontologies and enables the technologies to work with service environment; Green IT for efficient development and deployment of services and resources; Cyber-socialization to create opportunities in social-networking environment. In such competitive world of technologies to accomplishing the key objectives of intelligent communication and efficient on-demand sharing of resources, Internet of Things (IoT) and Cloud Computing have been emerged as widely studied and applied technologies. With the current trend, the future demands the integration of cloud computing and the expanding Internet of Things (IoT). In near

future, number of connected intelligent devices would be hundreds of times larger than the number of people connected. It is expected that in near future, more Internet traffic will be generated in compare to whole Internet used in current year.

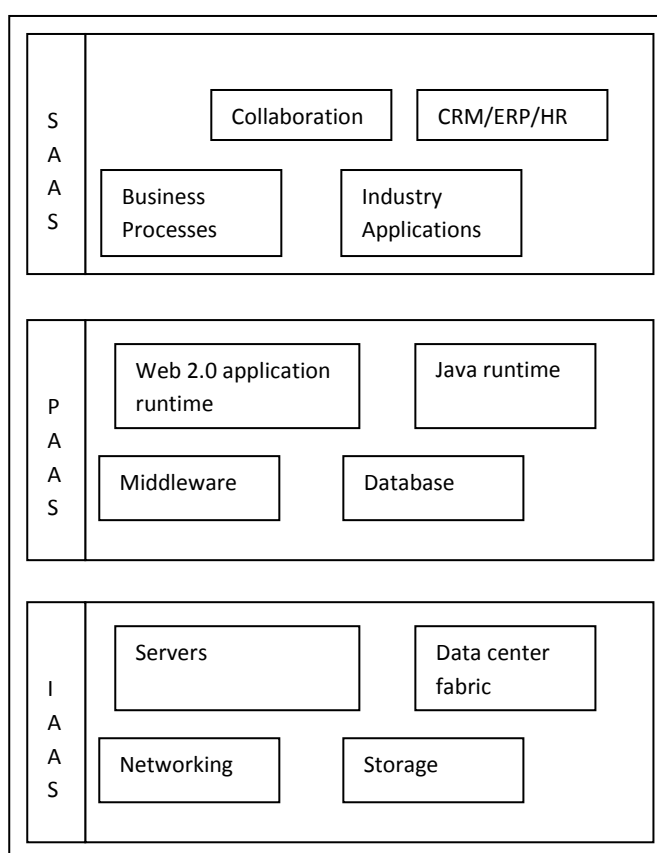


Figure 1. Overview of Cloud Paradigm

1.1 Cloud Computing

Cloud Computing is a recent trend and extended form of distributed computing, parallel computing and Grid computing. According to the definition provided by the National Institute of Standard and Technologies (NIST) [5]: "Cloud computing is a model to enable ubiquitous, ease-of-use and on-demand access to shared distributed resources and services" It lies on a pay-per-use model, where the users bear the cost of usage of services.[6][7][8]. The advantages of cloud computing is sharing of infrastructure, network access, minimal cost, reliability, flexibility and wide-range of services etc. [9]. Cloud provides a large pool of resources where the services are deployed with the help of Internet. The services are broadly classified into Software as a Service (SaaS):

where the application works over the Internet and user pay based on service usage, Platform as a Service (PaaS): to avail a platform to build applications and services, Networks as a Service (NaaS): to provide a wide range of virtual network(s), and Infrastructure as a Service (IaaS): to provide computation and storage services. [10][11][12]. The complete overview of cloud paradigm based on its services is represented in Figure

1. Cloud Computing has unlimited potential in terms of virtualized resources, storage, services and computation power. By applying the state-of-the-art review in this field and popularity of Cloud in recent years, the number of literature work has shown a tremendous growth since 2010. The Figure 2 shows a graph of number of papers related to cloud and its content.

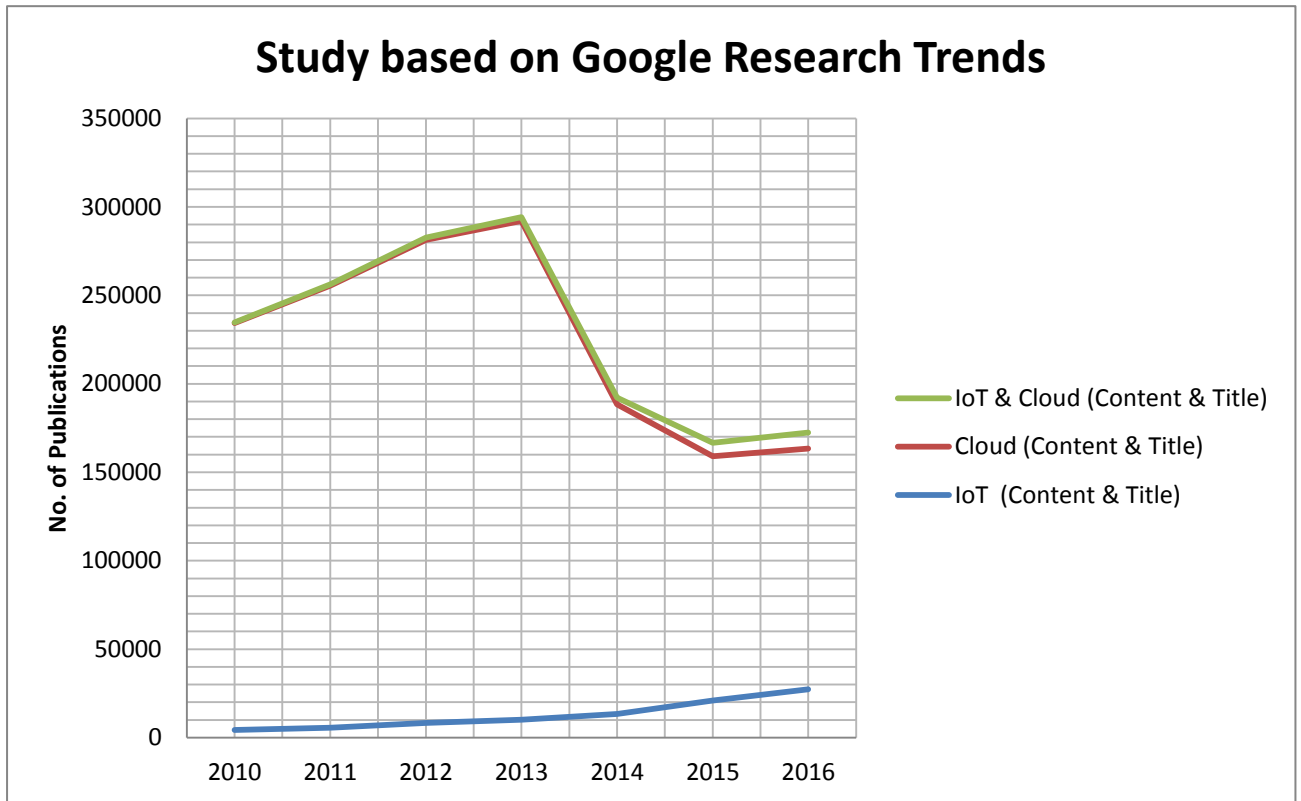


Fig.2 Research Trends of Cloud and IoT (By Content and Title)

1.2 Concept of Internet of Things:

IoT is a next revolution of computing outside the sphere of traditional world of desktop computing. IoT term was firstly introduced as a future of Internet and ubiquitous computing by Kevin Ashton in 1998 [13]. IoT is generally distinguished by real world small things or objects. Such objects transformed into communicating nodes over the Internet through the medium of data transmission e.g. Radio Frequency Identification (RFID) tags. IoT is a world-wide network of uniquely addressable interconnected objects, based on standard communication protocols” [14][15] that communicates over the Internet. IoT will play a vital role in the next future generation, while taking the scenarios of work and home. It will provide a full assistance of living, smart way of transportation, e-health etc. The IoT paradigm contains a 5-layer framework as shown in Figure 3. The Perception layer: lowest layer to collect and sense the data received from environment, Network layer: to collect the data from perception layer and send it to the Internet, Middleware: to provide service management and data storage. Application layer: Application layer presents the data in the form of: smart home, smart city, smart health, smart and other kinds of applications. Business layer: to provide business opportunities from the service being provided and to create further services. [13][16]

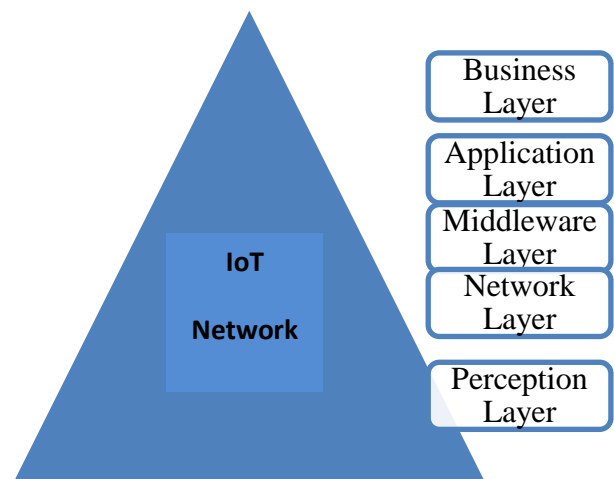


Figure 3. Overview of IoT Paradigm

The working of IoT applies on Machine-to-Machine (M2M) communications, but not limited to it. In IoT, even the passive entities can become a part. In IoT, the non-intelligent objects, named as ‘things’ become the communicating nodes.

Based on the google search trends various literature works have been found related to this next wave of computing i.e.

IoT. By applying the state-of-the-art review in this field and popularity of IoT in recent years, the number of literature work has shown a tremendous growth since 2010. The Figure 2 shows a graph of number of papers related to IoT and its content.

The later sections of this paper are organized as follows: Section II elaborated the Integration of Cloud and IoT, Research challenges are discussed in section III, Section 4 described the applications of Cloud IoT than the last section discussed about the concluding remarks and scope of future work.

2. CLOUD OF THINGS

In today's era, we are entering towards the world of web3 i.e. the ubiquitous computing web. Since 2011, number of connected devices has largely exceeded in compare to the number of people living on Earth. Overall, the connected devices have already reached 9 billion and are likely to grow more rapidly and reach 24 billion by 2020 [17]. Due to this rapid increase in connected devices, a lot of data is going to be produced. To store such a huge amount of data, there is going to be a need of rental storage space with efficient utilization and better processing. It is only possible with the integration of Cloud computing and IoT, which we can call as Cloud of Things (CoT). These two different and independent world of Cloud and IoT have some common advantages. On the one hand, the cloud provides unlimited storage and resources for better utilization and at the other end, the IoT deals with low cost and light weight things in the real world more dynamic way. It provides a wide variety of services by taking a large number of real life scenarios. These two paradigms are having independent evolution and complementary characteristics. Such characteristics are derived from literature [18] [19] and shown in Table I:

Table I: The Complementary derived Paradigm of Cloud IoT

Cloud Computing	Internet of Things
ubiquitous	pervasive
virtual resources	real world things
unlimited computational	limited computational
Virtually unlimited storage	limited storage
Internet for service delivery	Internet as a point of convergence
Manage big data	Source of big data

3. APPLICATIONS OF CLOUD IoT

In Cloud of Things will give birth to a novel set of smart applications and services, which will be strongly connected with our day to day life. This section discusses a wide variety of applications that will be made possible with the integration of CloudIoT paradigm.

1. **Healthcare:** The revolution of cloud of things paradigm has created several opportunities for medical IT and brought noteworthy improvements in the services of healthcare [20]. A huge amount of sensor data is generated by the healthcare applications that is required to manage for the purpose of analysis and processing. In such scenario, the cloud of things not only minimize the expertise requirements but also provide dominating solutions to manage healthcare data [20].

2. **Smart City:** Cloud of things provide future oriented services to acquire information from various heterogeneous infrastructures by accessing of all sort of IoT technologies and geo-locations. It provides further assistance for analysis and self management and control of big data from real world devices [21].
3. **Smart Home:** Applications of IoT are largely suitable in home environments, where it is used to automate the day to day in-house activities. Smart home devices generate solutions and provide services over the internet. It creates an internal network connection among the IoT devices by which the smart home devices can be remotely controlled and automated [22].
4. **Video Surveillance:** These types of services are largely used with security related applications. Here, Cloud of Things play a role to provide efficient storage, processing content of video sensors, management and for knowledge extraction from IP cameras [23].
5. **Smart Energy and Smart Grid:** Cloud of Things can effectively be used to offer intelligent services for energy consumption and distribution. It can effectively manage the energy level in the local and wide-areas. It provides a mechanism of self-healing, quality management and energy distribution [24].
6. **Automotive and Smart Mobility:** Cloud of Things create a promising opportunity to improve road safety, minimize road congestion, traffic management and vehicle recommendation with the help of integration of cloud technologies with WSNs, Satellite Network and RFID etc.[25]
7. **Environment Monitoring:** The integration of Cloud with IoT can also contribute in favour of environment such as continuous monitoring of water level, soil quality, civil structures (e.g. dams, bridges, and buildings), landslides, fire radiations and food quality etc. [26].
8. **Smart Logistics:** To provide an automated control for flows of goods between the origin and destination of receiver and to satisfy the requirements in terms of cost and time, the Cloud of Things play a vital role. It provides a geo-locating technology to automate the services of goods tracking and reduce the complexity of logistic systems [27].

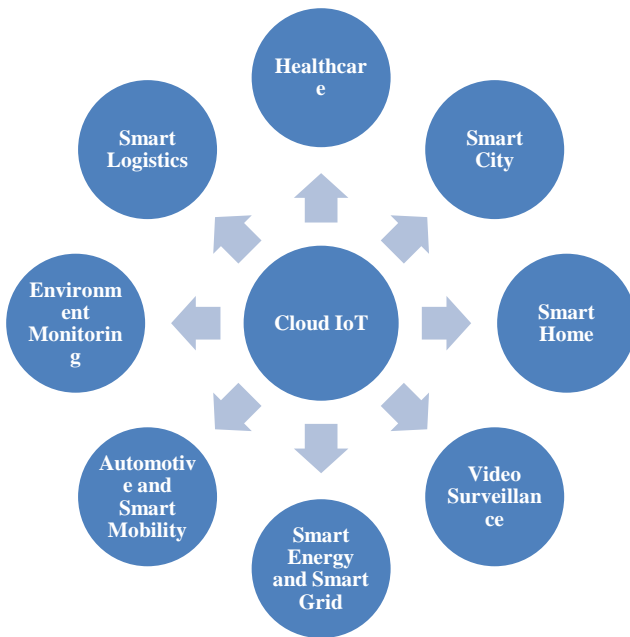


Fig 4. Applications of Cloud-IoT

4. RESEARCH CHALLENGES IN CLOUD OF THINGS BASED ON ITS APPLICATIONS

The integration of Cloud and IoT will not only create more research opportunities but also produce more business opportunities. But in practical, it is not going to be a simple task as it looks. There will be more number of research challenges and bigger security threats. In integration of cloud of things, different types of networks, services and data will be involved. Due to this heterogeneity, several key research challenges will be faced. These key research challenges are associated with the discussed applications of section 4.

5. CONCLUSIONS AND FUTURE WORK

The integration of Cloud Computing and Internet of Things represents a next big era of evolution in the world of Future Internet. This new revolutionary step will not only create the new directions for research but also open up the new exciting business opportunities. In this paper we have given a state-of-the-art study of new paradigm named as Cloud of Things. With Cloud of Things, our day to day life and activities will be potentially enhanced and become more exciting. Its advance applications i.e. Smart cities, Healthcare applications, Smart, Video Surveillance and Smart Energy etc. improve the quality of life. Since the adoption of Cloud of Things will bring the new challenges with their exciting new applications. Therefore, a brief analysis on research challenges associated with such applications are described and investigated further. Cloud of Things will give birth to new complex problems such as battle with efficient rental storage and development of applications associated with it, which will create new open issues and challenges in future.

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