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Research paper

Towards Cloud of Things from Internet of Things

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Abstract

The techniques Internet of things (IoT) and Cloud Computing (CC) are becoming a part of our day-to-day life; where IoT connects a billion numbers of devices to share the information by communicating each other and CC grants convenient, on-demand scalable network access in order to utilize the computing resources and it facilitates dynamic data integration from diverse sources. Both techniques are having their own pros and cons. So, a novel paradigm called cloud of things (CoT) is modeled by integrating the both CC and IoT, which enables a large number of applications to get advantages of IoT as well as CC. This paper delivers the basics of the technologies, motivations to model the cloud of things and its benefits. Also, it discusses the implementation challenges.

Keywords: *Cloud computing; Internet of Things; cloud of things; security; challenges.*

1. Introduction

Internet of Things (IoT) is a dynamic and wide-ranging network infrastructure of interconnected self-configuring nodes. It is fundamentally regarded as widely distributed, real world small things and it has limited storage and processing capacity to attain performance, security, reliability and privacy. In contrast, Cloud computing has almost boundless of storage and processing capacity, is an advanced technology and it has greater number of IoT problems at least partially elucidated [1], [2]. Accordingly, a new paradigm is innovated to heighten the both recent and future network development, is the integration of cloud and IoT, called Cloud of Things (CoT). This integrated technology carries the following characteristics:

On-market self-services: The services related to cloud always depend on the web and realizes the information deprived of any special benefits from society.

Wide range of network access: It provides diverse connectivity alternatives. The resources required for cloud can be collected via a wide range of network connected devices such as laptops, tablets and mobile phones.

Resource polling: It represents the way, how the information can be shared with the user at anywhere and anytime by means of the needed authorizations for gaining the access.

Elasticity: It describes about adding or removing the users, editing the software setup simply and quickly, networking and also delivers about the increasing storage space.

Measured service: It calculates the data usage like bandwidth, data storage and active user accounts in cloud space.



Fig. 1. Definition of IoT

2. Basic concepts

This section discusses basic concepts of Internet of Things and cloud computing along with its advantages and drawbacks, it delivers.

2.1. Internet of Things

IoT has been popularized since the last few years, and which refers to a world-wide network of uniquely addressable interconnected things/devices; identification of devices is based on the standard communication internet protocols [3], [4]. The key thought behind the IoT is, the people able to measure, understand, infer and even is able to modify the environmental things what are all ubiquitously presented around them as shown in Fig.1.

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IoT is operated by the advanced communication technologies and variety of devices, rather things incorporated in IoT are not only complex devices like mobile phones, instead it also includes day-to-day objects like clothing, furniture, landmarks, paper, monuments, work of art, etc [5], [6]. These things act as actuators or sensors, which are able to work together with each other to accomplish a goal.

The main feature of IoT is its influence on daily life of users [7]. It has incredible effects in home scenarios as well as work scenarios such as assisted living, e-health, and smart transportation etc. A few key aspects of IoT are described below:

RFID: Radio-Frequency Identification (RFID) system is main component in any IoT model, which incorporates one or more readers and several tags. It helps in automatic identification of anything they are attached to and allow objects to be assigned unique digital identities, to communicate with digital services. RFID tags don't require on-board power supply, but it consumes power from batteries [7], [8].

Sensor Networks (wireless): It contains a huge number of sensing nodes, and their communication takes place in multi-hop fashion. Special nodes called sinks are used to collect the results. Wireless sensor networks (WSN), provides various data that are being utilized in government and environmental services, defense and healthcare etc. It also may face many issues like security, reliability, privacy, storage capacity, bandwidth etc [7], [9].

Addressing: The evolution of internet led the people to interconnect unprecedentedly, but now the trend is to interconnect the object to make to the environment as smart [10]. In this regard, things or objects needs to be uniquely identified, this unique identification can be addressed by IPv4 and IPv6.

Middleware: Since the limited storage and processing capabilities, the participation of objects in the network is heterogeneous. So, the middleware plays a key role between the things and the application layer, in order to provide the functional abstraction. The middleware consists a set of object abstraction service management, service composition and application layers as shown in the Fig. 2 [5].

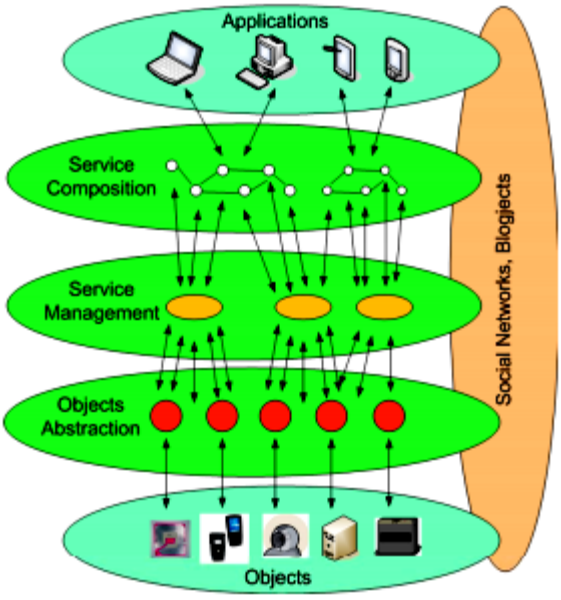


Fig. 2: Middleware architecture of IoT

2.2. Cloud Computing

Cloud computing is a disruptive technology with insightful implications to bring the various internet services. Large companies like google, amazon, facebook, etc. widely took this paradigm for delivering services via the internet, also gaining both technical and economical benefits. Even though some of issues have been found in each service models, those are associated to security, privacy and service-level agreements, which might be an alarming issues of potential users [11]. Also, the lack of standard APIs prevents the customers to simply fetch the code and data from a site in order to run in another. Fig. 3 précises the cloud service models and its benefits by means of layered architecture fashion.

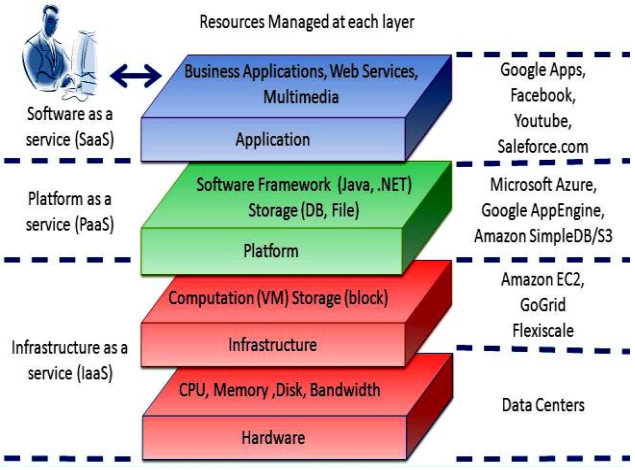


Fig. 3: Cloud computing: layered view

The architecture of cloud contains four layers; they are data centre (hardware), infrastructure, platform and application [12], [13]. Cloud services are divided as follows:

Software as a Service (Saas): It denotes the functioning of applications over the cloud.

Platform as a Service (PaaS): It denotes platform layer resources.

Infrastructure as a Service (IaaS): It refers the resources such as network, storage and processing. It permits the consumer to govern the storage, operating system and applications.

Types of Clouds: As stated in the literature, cloud can be various types. They are:

(i) Private: It is used typically owned, operated a managed by sing organization.

(ii) Public: It is provisioned to custom usage by the public.

(iii) Hybrid: It is a combination of more than one distinct cloud structure.

(iv) Virtual Private: It aims to addressing the issues related to public and private clouds. It permits the owners to format the network settings by their own.

As each type of cloud has its own pros and cons, selection of the cloud model is based on the required business consequence. CC is attractive, as it free for the infrastructure invest, renting resources along with needs and usage. It permits to decrease operating cost and their load. Moreover, it has a number of benefits in terms of energy efficiency, resource utilization, elasticity, flexibility and performance isolation.

3. Cloud of Things (CoT)

The two technologies IoT and Cloud have got a lot of advancements [11]. It has unique characteristics, as Table 1 depicts. Such dissimilarities has induced the researchers to put forward a novel technology; an integration of cloud and IoT called Cloud of Things (CoT).

Table 1 Different aspects of Cloud and IoT

Various aspects	Cloud	IoT
Reachability	Centralized	Universal
Displacement	Ubiquitous	Restricted
Components	Virtual resources	Real-world
Computations	Virtual and unrestricted	Restricted
Role of the internet	Delivery service	Point of coverage
Storage	Virtual and unrestricted	Restricted
Big data	Manages	Storage

Typically, IoT can improve their technological constraints (processing, communication, storage) from the virtual unlimited capabilities and resources of cloud, whereas, cloud can extend its scope by dealing with real world things in a more dynamic and distributed routine. Also, it can delivery new services of the everyday life developments. In most of the application cloud acts as intermediate layer in the middle of the applications and the things, for hiding all the complexity and functionalities require to implement it. This will influence the upcoming development, where information gathering, dispensation and transmission may cause new meets [14]. Even though IoT characterized by a very high heterogeneity of devices, protocols and technologies, it lacks in various essential properties, reliability, scalability, efficiency, security, interoperability and flexibility [15], [16]. Cloud simplifies IoT data collection and processing, also empowers quick setup and amalgamation of new things at lower costs for devolvement and data processing [15]. The other advantages of CoT are follows:

Communication: Sharing of data and application are the main aspects of CoT paradigm. Ubiquitous applications can be transfer via IoT, where data collection and distribution by the automation can be done at low-cost. Cloud facilitates an effective solution to establish a connection, tracking and managing any things from anywhere at any time using built-in apps and customized portals [17], [18].

Storage: IoT involves in a large volume of information bases, which in turn generates a plethora of semi or non-structured data called big data [14]. Big data have the following characteristics [16]: data size, type and velocity. Data generated by the IoT is handled by the cloud as it is more flexible and also cost effective [17].

Processing computations: IoT has restricted processing and energy resources, whereas cloud facilitates virtual unlimited processing and on-demand utilities[19].

Scope: As billions of users communicating with each other's and accumulating a variety of information, we can say that the world is rapidly moving in the direction of Internet of Everything (IoE) arena- a network of networks unprecedented opportunities and also new risks. CoT paradigm facilitates to the new smart services and extends the cloud applications via the things [2], [17], also giving introduction to the Things as a Service paradigm [20], [21].

New meets: CoT empowers new developments for smart applications, objects and services[9], [15], [22] Some of the new meets are following:

- ✓ SaaS (Sensing as a Service): It deals with sensor data
- ✓ EaaS (Ethernet as a Service): It provides connectivity to handle remote objects/ devices
- ✓ SAaaS (Sensing and Actuation as a Service): It gives automatic control logics
- ✓ IPMaaS (Identity and Policy Management as a Service): It deals with identity management and policies.
- ✓ DBaaS (Database as a Service): It manages the databases.
- ✓ SEaaS (Sensor Event as a Service): It dispatches the sensor event messages
- ✓ SenaaS (Sensor as a Service): It manages the remote sensors
- ✓ DaaS (Data as a Service): It facilitates the access to any kind of data.

4. CoT Applications

The integration of cloud and IoT (CoT) has given a birth to a new set of smart applications and services and it can impact our everyday life as shown in Fig. 4.

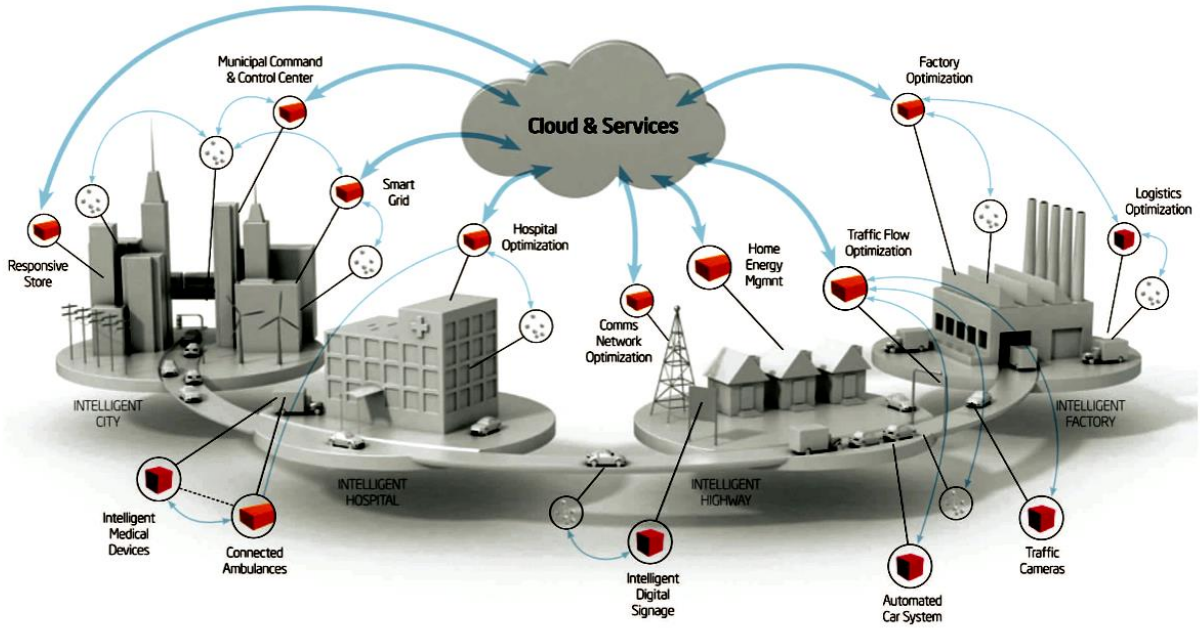


Fig. 4: Applications of CoT [11]

Table 2: Applications of CoT

Application	Description
Smart city	The generation of smart city services enables the interaction of surrounding environment and it creates new opportunities for contextualization and geo-awareness.
Healthcare	It brings many innovative services like collecting patients' data from medical devices of network connected sensors, storing and processing of those data in cloud as Electronic healthcare records. (intelligent medicine control and hospital management, smart wearables for health monitoring)
Smart home	It adopts various embedded devices and cloud services to bring out the automated home applications like security control, smart metering.
Video surveillance	Complex video analytics need cloud solutions (VSaaS) for video storage and processing [23].
Automotive and mobility	It brings many benefits like increasing road safety, managing traffic and parking, reducing road congestion, vehicle warranty analysis [24].
Smart grid and energy	It enables consumer with smart management of energy consumption (renewable energy resources)
Smart logistics	It makes easy of goods transition from producer and consumer by enabling tracking the transits of goods.
Environmental monitoring	It enables the entity that monitors the wide area of environment and sensors like pollution source monitoring, air quality monitoring and water quality monitoring.

5. Challenges

The previous section discussed the benefits and improvement in applications conquered by the integrated technology CoT. This section discusses the challenges behind the improvement of application scenarios [14]. Those challenges are elaborated below:

Privacy and security:
When some of IoT applications upgrade with cloud, issues arise because of the discrepancy in the knowledge about physical location of data, trustiness in service provider, and knowledge of service level agreements [25]. Such applications may undergo to the attacks namely SQL injection, session riding, cross site scripting and side-channel and also it may affect by the vulnerabilities such as virtual machine escape and session hijacking. The computing power constraints imposed by the things do not allow employing the public key cryptography also.

Heterogeneity:
The important and non-negligible challenge is heterogeneity of platforms, devices, operating systems and services. The interaction with huge amount of heterogeneous things has to be properly identified in the cloud among the various levels. This challenge comprises the aspects in terms of interoperable programming interfaces [26], unifying platforms and middleware, and copying with data diversity [25], etc.

Performance:
The main challenge is obtaining a stable network performance. For instance, if the broadband increases, it is not easy to follow the storage and computation [13], [17]. As timeliness is heavily impacted with unpredictability issues, real-world applications might be affect extensively.

Reliability:
When CoT is implemented for mission-critical applications, reliability issues usually rises. For example, vehicular networking and communication is unreliable [27].

Big data:
The integration of cloud and IoT clearly states that IoT will be a one of the source of data (big data) and the cloud can facilitate to store that data for a long period of time [10]. Handling such a large volume of data is an issue, as the performance of application is heavily subject to the properties of data management service. Defining a solution for resolving the data management issues is still a big challenge [19]. Moreover, data integrity is a significant issue, due to service quality, security and privacy challenges [28].

Legal aspects: It is very important in certain research applications. For example, service provider should adopt for international regulations and users should offer certain donation to data collection [29].

Monitoring: It is an essential task in cloud for dealing resources, planning the capacity, performance and security and troubleshoot-

ing also [30]. CoT take over the monitoring task from cloud, but it may get affect by volume and velocity features of IoT.

Large scale: CoT can design the new applications by analyzing and integrating information spreading out from devices like sensors [31–33]. Some applications internally require the interaction with a large number of devices like distributed area environments. This large scale of systems makes the usual challenges harder to overwhelm.

6. Conclusion

This paper presented the applications and challenges of integrated technology, cloud of things (CoT). First, it discussed the basics of IoT and cloud computing along with its pros and cons. Also, it described the thing that strived to integrate technologies. CoT paradigm will be enhanced for every applications and services too. It can promote improved healthcare and smart city applications, business openings, etc. The challenges like scalability and security; the heterogeneity of devices and technologies; legal aspects and privacy preservation behind CoT is also discussed. The future research direction of this integrated technology may include the large support in communication models, security related software like firewalls, intrusion detection, surveillance, identification of managing the naming and addressing the things.

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