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Cloud of Things

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Abstract This chapter provides an introduction to the cloud of things paradigm. It begins by providing a general overview on IoT and cloud computing. It presents the concept of CoT. It presents some applications, benefits, and challenges of CoT.

Keywords cloud of things, cloud of things

Introduction

Cloud computing and Internet of things (IoT) are among the hottest trends in ICT. They are gaining importance and becoming part of our daily lives. Cloud computing (or cloud) is a computing model that allows users to have access to resources on a pay-as-you-use basis. Cloud computing is extended form of distributed computing, parallel computing, and grid computing. It provides ubiquitous access to the content, without the hassle of keeping large storage and computing devices.

Internet of things (IoT) is a recent technology and is less mature than cloud computing. IoT consists of not just hardware and software, but it also includes interaction and social aspects. It consists of sensors and devices embedded in physical objects. Currently IoT is facing a number of challenges related to scalability, interoperability, storage capacity, processing power, and security. Cloud computing is capable of handling all these challenges, thus leading towards cloud of things (CoT), which is the integration of cloud and IoT. Thus, cloud and IoT are the primary complementary elements of the future Internet. The integration of cloud with IoT will allow IoT systems to have access to unlimited storage and processing capabilities [1].

Overview of Internet of Things

The term "Internet of things" was introduced by Kevin Ashton from the United Kingdom in 1999. Internet of Things (IoT) is a network of connecting devices embedded with sensors. It is a collection of identifiable things with the ability to communicate over wired or wireless communication. The devices or things can be connected to the Internet through three main technology components: physical devices and sensors (connected things), connection and infrastructure, and analytics and applications.

There are four main technologies that enable IoT [2]:

(1) Radio-frequency identification (RFID) and near-field communication (NFC). RFID technology can also help in the tracking and monitoring. The most valuable use of NFC is contactless installment.
(2) Optical tags and quick response codes: This is used for low cost tagging.
(3) Communication systems (such as Wi-Fi and ZigBee), which may include wide area networks (WANs) and personal area networks (PANs).

(4) Wireless sensor network (WSN): Several IoT devices use a large numbers of sensors to collect data and then make intelligent decisions. WSN is used to monitor physical properties in specific environments. Sensors can monitor temperatures, pressures, chemical, and humidity.

These technologies enable devices to be smart. A typical IoT is shown in Figure 1 [3]. Other related technologies are cloud computing, machine learning, and big data. Cloud computing and IoT are tightly coupled. The growth of IoT and the rapid development of associated technologies create a widespread connection of "things."

Figure 1: A typical Internet of things [3]

The emergence of IoT is shaping and reshaping the definition of future services. IoT helps people and communities by making their systems smarter and their lives easier, more secure, and safer. IoT transforms ordinary products such as cars, buildings, and machines into smart, connected objects that can communicate with people and each other. IoT technologies have been utilized in several areas such as education, transportation, logistics, manufacturing, agriculture, urban computing, home automation, and healthcare. These applications have given birth to smart everything, smart cars, smart homes, smart refrigerators, smart cities, smart parking, smart health, smart factory, smart environment, smart transportation, smart shopping, smart agriculture, smart lighting, smart grid, and smart energy.

Overview on Cloud Computing

Cloud computing (CC) is a computing paradigm for delivering computing services (such as servers, storage, databases, networking, software, analytics, and more) over the "the cloud" or Internet with pay-as-you-go pricing. Hence, "cloud computing" is also called "Internet computing." The term "cloud computing" was introduced in 1961 when computer scientist John McCarthy predicted that computing would become a public utility.

Although cloud computing is a relatively recent concept, it is quickly becoming a necessity in many industries. Cloud computing presents several characteristics such as [4]:

- The pooling of resources

- Better use of resources
- Elasticity
- Dynamic (Distributed)
- Scalability
- Virtualized

From a service point of view, cloud computing includes three models: software, platform, and infrastructure [5].
(1) *Software as a service* (SaaS): The applications are hosted by a cloud service provider and made available to customers over the Internet. As a SaaS, the cloud can offer healthcare organizations on-demand hosted services.
(2) *Platform as a service* (PaaS): The development tools (e.g. operation systems) are hosted in the cloud and accessed through a browser. Using a PaaS environment, Microsoft provides a service to supply providers with networks, servers, and storage.
(3) *Infrastructure as a service* (IaaS): Cloud service providers set up huge infrastructure like servers, storage devices, hardware, etc. to be used by potential clients.
There are four cloud computing deployment models [6].
(1) *Public cloud*: A public cloud is a publicly accessible cloud environment owned by a third-party cloud provider. The service provider makes resources available to the general public over the Internet on a pay-as-you-go basis.
(2) *Private cloud:* A cloud infrastructure is owned and operated solely for a single organization. Organizations build their own cloud infrastructure for use by their business units.
(3) *Community cloud*: A community cloud is similar to a public cloud except that its access is limited to a specific community of cloud consumer. The cloud infrastructure is shared by several organizations with common concerns.
(4) *Hybrid cloud*: A hybrid cloud is a combination of a public and private cloud.
An example of cloud computing is shown in Figure 2 [7]. Cloud computing is an increasingly popular service that offers several advantages to IoT. Due to its on-demand nature, cloud computing is available for use anytime and anywhere. The complementary characteristics of cloud computing and Internet of things are shown in Table 1 [8]. Integration of IoT with cloud computing is becoming very important.

Figure 2: An example of cloud computing [7]

Table 1: The complementarity of IoT and cloud computing [8]

Internet of Things	Cloud Computing
Pervasive	Ubiquitous
Real world	Virtual resources
Limited computational	Unlimited computational
Limited storage	Unlimited storage
Point of convergence	Service delivery
Big data source	Means to manage big data

Concept of Cloud of Things

Over the last years, IoT and cloud computing have evolved gradually. IoT is becoming so pervasive that it is becoming important to integrate it with cloud computing. The Internet of things is the objective, while cloud computing is a means of realization. The cloud compensates the limitations of IoT such as processing, energy, and storage. Integrating IoT with cloud will provide flexibility, scalability, and robustness to the entire system.

This amalgamation of IoT and cloud computing is known as cloud of things (CoT) or cloud of everything. The concept of a "cloud of things" was introduced by Sanjay Sarma at MIT in October 2012. The concept appears simple: combine all the data from the distributed network of IoT devices, analyze it, and take action. In CoT, IoT devices are connected to the clouds via the Internet for data storage, processing, analytics, and visualization. The combination of cloud computing and IoT has drawn quite attention from different areas such as devices virtualization and service provisioning. CoT provides virtually unlimited cloud services to enhance the large-scale IoT platforms. The CoT has emerged as a promising technology to integrate the distributed physical resources and manage the things in terms of cloud services in a scalable, flexible, and reusable manner. A typical cloud of things is shown in Figure 3 [9].

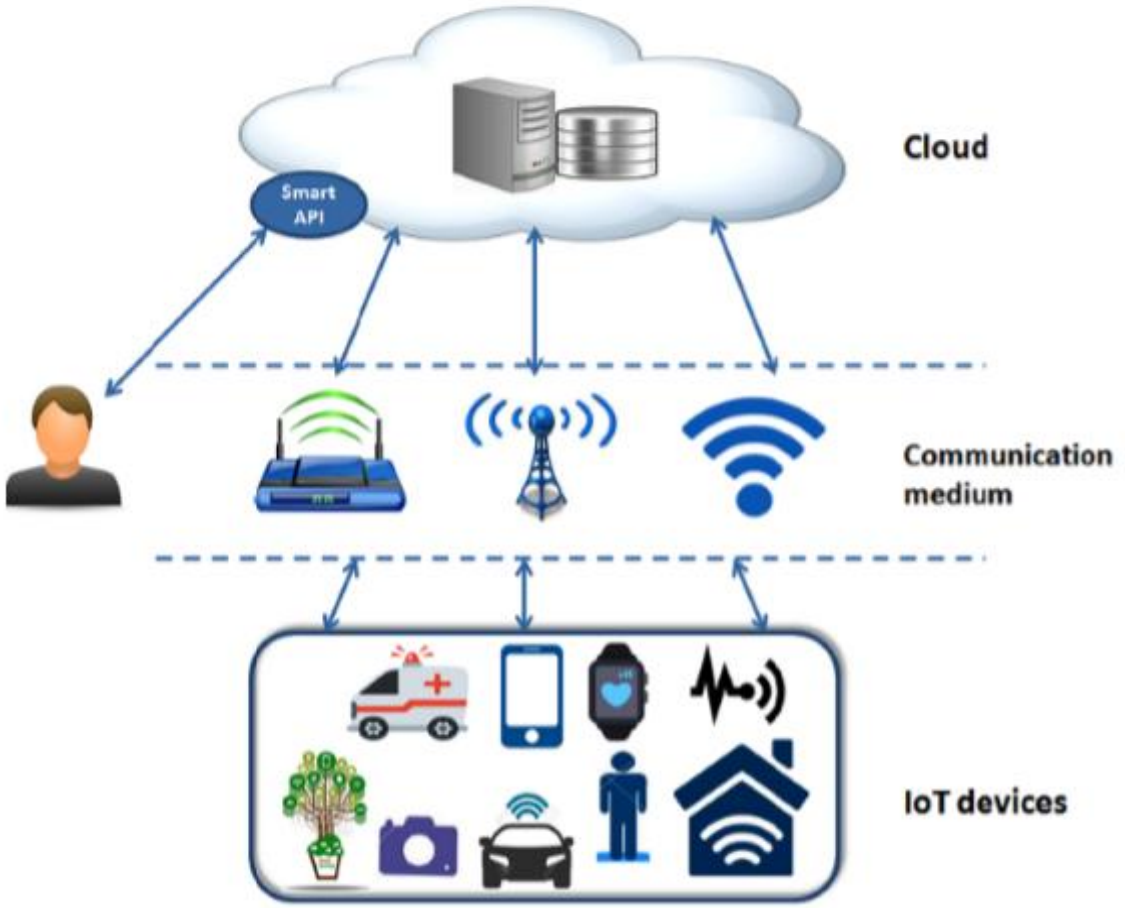

Figure 3: A typical cloud of things [9]

The cloud of things is a smart technology which allows the access of services or anything over the Internet at anytime, anywhere. It permits moving services from the cloud to the IoT devices in real-time. It is the virtual domain to realize the concept of IoT applications. As a platform, CoT allows intelligent usage of collection of applications, information, and infrastructure in a cost-effective manner.

Applications

The cloud of things paradigm is perceived as a promising enabler of many real life applications. There is no one-size-fits-all solution for CoT. Each company must consider their specific application and decide if the cloud

is useful for them. The CoT concept has expedited the development of smart services resulting in the proliferation of deployments like smart city, smart home, and smart building. CoT has number of applications including healthcare, smart cities, smart homes, smart logistics, smart irrigation system, video surveillance, energy, agriculture, and advanced manufacturing. Some of these applications are shown in Figure 4 [10] and explained below.

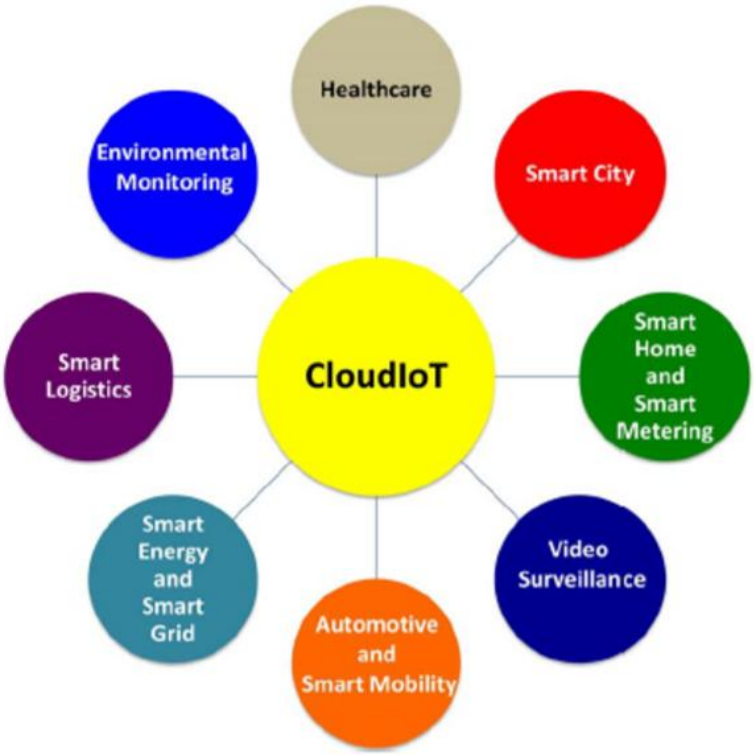

Figure 4 Some applications of CoT [10]

- *Smart city:* Big cities around the world plan to adopt the smart city concept to enhance the quality of life of their residents. The concept of smart city involves monitoring, controlling, and managing the conditions of all of the city's critical infrastructures, while providing quality services to the citizens. A city will likely deploy many IoT applications such smart transportation, smart energy, smart water management, etc. These applications will produce very large data volumes. Cloud integration enables the city to host these applications in a cost-effective way. The CoT can provide a platform for operating different types of smart city services. In CoT, all objects of smart cities such as residents, vehicles, streets, buildings, hospitals, and energy and water plants are interconnected through the IoT [11].
- *Healthcare*: The healthcare sector has witnessed a tremendous deployment of a wide variety of sensors to monitor the health of patients. There will be an application running on the cloud to detect the behavior of the patients and alert the healthcare professionals on the situation. The elderly at home can be remotely monitored to receive healthcare support. The use of CoT in healthcare domain offers new opportunities and can enhance healthcare services [9,12]. The main goal of using CoT to provide Healthcare-as-a-Service built is to provide seamless monitoring of the patients' health at the hospital or at homes in a timely care.
- *Agriculture:* CoT-based systems play an increasingly important role in a number of real-world applications, such as smart agriculture. Deployment of a CoT network in smart agriculture can make use of energy more efficient and less costly. Cloud-based smart irrigation system can provide a number of benefits [13].
- *Supply Chain*: Various suppliers, providing respective services, gather together to realize the supplier cloud for supply chain management. The supply chain management consists of four parts: supplier management, warehouse management, logistics management, and client management. Highly

distributed warehouses and heterogeneous resources located in each link of supply chains may increase the complexity of supply chain integration and management. The concept of CoT guides the development of the whole supply chain integration and management. In the CoT environment, the supply chain resources are virtualized and encapsulated into cloud services [14].

- *Smart homes:* These are the highest-ranking IoT applications as more companies are actively involved in building smart home applications. Applications can range from providing basic home automation like controlling heating, ventilation, doors, windows, lights, home appliances, watering systems, etc. Smart homes equipped with sensors can also detect the behavior of family members. CoT deployment will enable devices to communicate efficiently with the many sensors in order to perform and deliver timely results [15].

Benefits

There are several benefits of using the cloud for CoT applications. These include [16]:

- Decreased costs, both upfront and infrastructure
- Pay-as-needed for storage/computing
- High system scalability and availability
- Increased lifespan of battery-powered sensors/devices
- Ability to aggregate large amounts of data
- Anything with an Internet connection can become "smart"
- Allows you to automate your operations effectively, boosting efficiency
- Enables your company to remain competitive in the future
- Requires fewer personnel and keeps costs under control.

The cloud of things allows you to automate your operations easily and effectively. It also allows you to turn products into innovative services, and remain competitive. You can let your customers have limited access to your CoT platform [17]. CoTs provide means to handle increasing data and other resources of underlying IoTs. It allows you to remotely monitor and control your connected devices.

Challenges

New challenges arise when cloud is integrated with IoT to form CoT. The challenges are mainly due to the conflicting properties of IoT and cloud infrastructures. It will not be easy for everything to become part of IoT and then having all the resources available through cloud computing. Some of the challenges are reliability and availability of CoT services, insecure cryptography, data protection and portability, and Internet dependency. Security is a key factor that mainly hinders the growth of CoT. This has been defined as a set of mechanisms to protect sensitive data from vulnerable attacks and to guarantee confidentiality, integrity, and authenticity of data [18]. In certain IoT applications, latency can be critical. Time sensitive data should be stored in the closest possible physical location to the user, so that minimum possible time is required to access it.

Other issues include the following [19-21]:

- *Protocol support*: Connecting different things to the Internet will require using different protocols
- *Energy efficiency:* Due to its ubiquitous nature, CoT is continuously draining energy from resources.
- *Lack of standards:* There are no standards for IoT sensor data. Data schemas vary with manufacturers, presenting challenges establishing a common format.
- *Data ownership:* This is of importance for IoT applications involving personal data such as healthcare.
- *IPv6 deployment:* This will be an issue if IPv6 is to be used for the identification of communicating devices.
- *Location of data storage*: Location matters for critical and latency sensitive data, such as video.
- *Resource allocation:* It is difficult to identify what resources assigned to any particular IoTs.
- *Quality of service:* The heterogeneity among the IoT devices requires adaptive QoS constraints that can deal with all kinds of traffic demands.

Conclusion

Cloud computing and Internet of things are among the hottest trends in ICT. Although the two worlds of cloud computing and IoT have seen independent evolution, their characteristics are complementary. Their amalgamation of two revolutionary paradigms, known as Cloud of Things, is becoming very important. CoT is a newly emerging technology that bridges cloud computing and IoT. It can handle the ever increasing size of the Internet. It will create more research and business opportunities. It is the future of the IoT. CoT will definitely grow and can help achieve the goals of envisioned IoT and future Internet. The technology is expected to disrupt both current and future Internet. More information about CoT can be found in the book [22].

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