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A Review and Comparative Study of Cloud Computing and the Internet of Things

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ABSTRACT

The Internet of Things (IoT) and cloud computing are two distinct ideas that are impacting our lives in various ways and will continue to be utilized and emphasized in the future of the Internet. These two ideas are combined and compared in this study. IoT and cloud computing have received independent attention in numerous research. However, these studies do not go deep enough into its combination which gives rise to new problems. IoT is experiencing increasing development as the next Internet evolution. IoT allows billions of devices to interact with each other and assign more value to our daily lives. In this paper, we present a literature review of cloud computing and IoT. First, we examine the fundamentals of cloud computing and IoT. Then, we talk about how they complement one another and what are their main differences. IoT can greatly benefit from the abundance of resources found in the cloud.

1. Introduction

Cloud computing is not considered the Internet of Things (IoT) itself, but it is a close companion providing core functions for most elements. New forms of cloud computing technologies have revolutionized the process of creating, storing, and accessing knowledge [1]; for instance, social media, instant messaging, social networking, web conferencing, and cloud storage technologies such as Dropbox and Google Drive. IoT is a growing research area where overall opportunities are boundless [2]. IoT means the network of devices/operations that are adhered to all the network components including the layers of hardware, software, and connectivity of a network [3]. Cloud computing is a phenomenon of developing and integrating on-demand, elastic, and geographically dispersed computing resources [4]. Currently, there are so many cloud service providers, and they mostly concentrate on these fields [5]. Also, it is expected that the advancement of IoT innovation can be improved by the appearance of cloud computing as well as all its applications within the fog context taking into consideration the growth of smart product usage [6].

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2. Fundamentals

2.1 IoT

It has been confirmed that IoT can aid in enhancing certain processes to be more of a type that has a parameter by which it can be easily measured through the collection and analysis of a large amount of data [7]. IoT has the opportunity to improve human lives in various facets such as medical care, smart cities, construction fields, farming, water systems, and energy departments. In both academia and industries, IoT emerges as an interesting new technology space [8]. Mostly, physical and miniature IoT with modest capability and storage capacity provide challenges to performance, dependability, security, and propriety [4]. The concept of cloud possesses truly innumerable possibilities in terms of computation and storage.

The term "IoT" describes how unusual products, like computers, are connected to the network. Through the IoT, cars, kitchen appliances, and other sensors can be connected. Change is made possible by the IoT. Its infrastructure makes it possible to automate equipment and systems in an intelligent, economical way that supports real-time control and monitoring. Having access to all pertinent data (both historical trend data and real-time information) allows for creative combination and processing of the data, leading to more effective control or decision-making [9].

The advantages of IoT are: 1) connectivity, 2) efficiency, 3) monitoring, 4) improved productivity, and 5) cost-effectiveness. On the other hand, the disadvantages of IoT are: 1) security and privacy issues, 2) illegal access, and 3) security of sensor-node breach.

Different IoT layers are (Figure 1):

i. *Sensing layer* – It can sense the environment on its own. This can be done on a tag or a sensor that has smart systems in the sensing layer to exchange data between the devices.
ii. *Network layer* – In the networking layer, the following issues like qualitative standards, technologies for processing and searching data, as well as safety and privacy should be addressed.
iii. *Service layer* – This is an economic platform as the use of hardware and software is repetitive. Services in the service layer directly work in the network to effectively search for new application services and get dynamic data about services.
iv. *Interface layer* – It is carried out on the application frontend or application program interface [2].

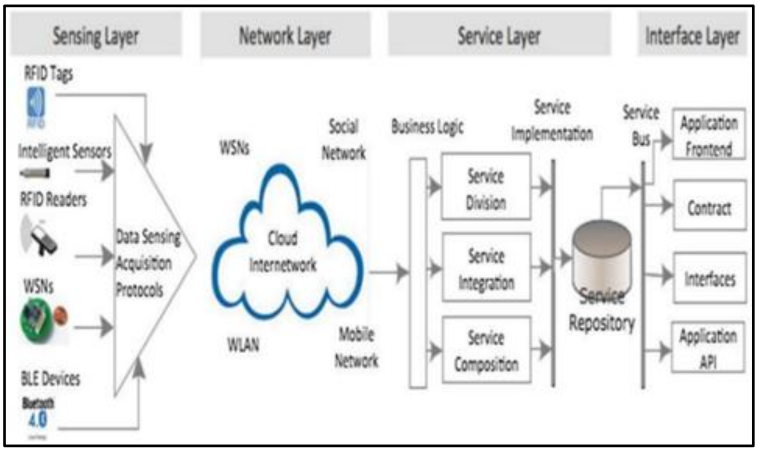

Fig. 1. IoT infrastructure

Uses of IoT are:

i. *Smart cities* – Smart city technologies alleviate problems with public safety and environmental concerns while streamlining routine tasks; e.g. smart utility meters, smart waste management systems, and smart grids.
ii. *Smart transportation* – Drivers are drawn to features like voice search and location data, and as smart applications develop and expand, so too will the use of smart transit.
iii. *Smart home* – Houses are equipped with a smart home system that can be operated remotely and links to your appliances to automate certain chores.

2.2 Cloud Computing

Cloud resources can include virtual computers, memory, CPU power, storage, and network throughput as well (Figure 2). To cut the expense of running services, cloud computing presents a chance of employing reconfigurable computing middleware at a remote place as well as reducing manpower [4]. This makes the IoT prototype, which is an active multivendor network (infrastructure), regarding the smart self-configuring sensors (objects) [5].

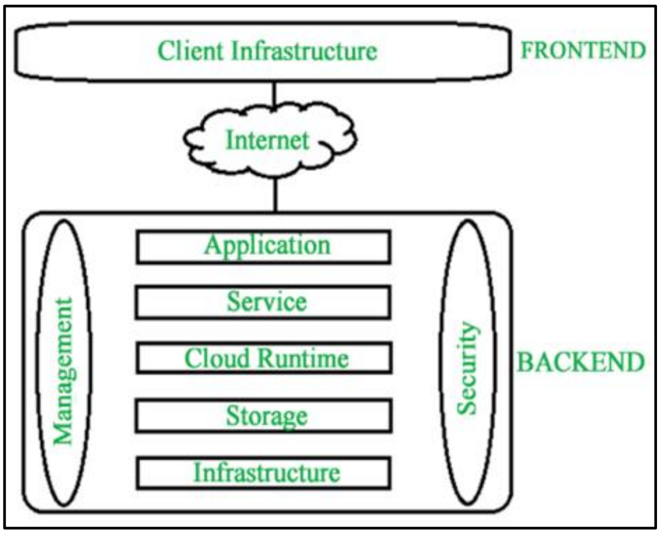

Fig. 2. Cloud infrastructure

The on-demand supply of shared, scalable IT resources—such as servers, storage, databases, networking, analytics, and intelligence through the Internet is known as cloud computing. By using virtualization technology, cloud services are made available to users at different locations through data centers, offering benefits to the end user. Based on virtualization technology, it can decompose and regroup the original computing and storing capacity of the current server to enhance the usage efficiency and dispatchability of IT resources. Based on a contract with the owner, users only pay for the services rendered. Cloud computing has become a dominant business model for delivering IT infrastructure, components, and applications.

The advantages of cloud computing are: 1) more affordable computers for end users, 2) enhanced output, 3) reduced costs for IT Infrastructure, 4) fewer problems with maintenance, 5) cheaper software, 6) instant updates for software, 7) a rise in processing capacity, 8) an infinite storage capacity, 9) better protection of data, 10) greater operating system compatibility, 11) enhanced compatibility with document formats, 12) simpler group cooperation, 13) document accessibility for all, 14) access to the most recent version, and 15) breaks the link to particular devices. On the other hand, the disadvantages of cloud computing are: 1) needs to be connected to the Internet at all times, 2) not suitable when net speed is slow, 3) may be sluggish, 4) features could be restricted, and 5) the information that can be stored could not be secure.

Cloud computing has several services available, and users can avail of them according to their needs. These services are:

i. Software as a Service (SaaS) – A third-party provider hosts the program and enables rapid access to it without the need to set up new infrastructure.
ii. Platform as a Service (PaaS) – A third-party provider hosts the program and allows immediate access to it that would require the creation of some new hardware if it was done on our own.
iii. Infrastructure as a Service (IaaS) – A vital model to announce the organization service to make the service reachable for the client and application for running the service.

There are three different types of cloud, each of them running on different protocols and requirements:

i. *Public cloud* – Public clouds are controlled and managed by organizations, which utilize them to provide others quick and cheap access to computing resources. Public cloud service customers do not need to invest in any tools, equipment, or systems as these are owned and maintained by the suppliers.
ii. *Private cloud* – Private clouds are data center architectures with automation, monitoring, provisioning, scalability, and flexibility that are owned by a specific company.
iii. *Hybrid cloud* – A hybrid cloud combines two or more clouds (i.e. public, private, or community) to provide the benefits of various deployment types while maintaining their individuality.

2.3 Fog Computing and IoT

The integration of the cloud and the IoT, known as the Cloud of Things (CoT), provides numerous advantages [10]. The CoT paradigm is not simple. It presents new difficulties for the IoT system that the conventional centralized cloud computing architecture is unable to handle. These difficulties include latency, capacity limitations, devices with limited resources, network failure with sporadic connectivity, and increased security. Furthermore, the centralized cloud method is inappropriate for IoT applications with time-sensitive operations or inadequate Internet access. Resources for computation, storage, and networking serve as the foundation for both the cloud and the fog [11].

Cisco first proposed the idea of fog computing in 2012 [12]. Fog computing is an emerging distributed computing system that extends the cloud by bringing the computing capabilities closer to the physical and virtual entities [13]. Fog computing is still a relatively new paradigm. Numerous studies are being undertaken today to enhance particular aspects or qualities, such as interactions between the devices or between the fog nodes, security and privacy of the stored and shared data, the volume of data to be transmitted, and the places and manners for processing the information to meet the needs of the IoT [14]. Figure 3 illustrates how IoT devices are connected to fog computing and how other devices and technologies are being used throughout the process.

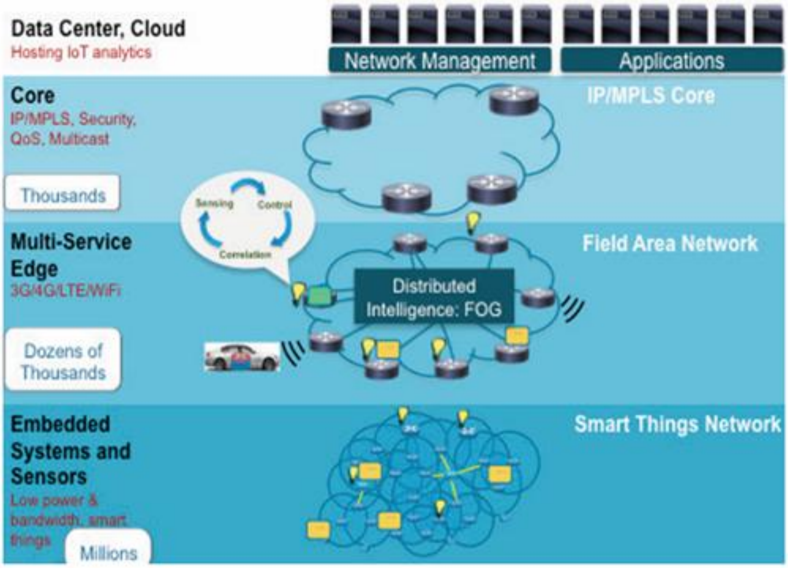

Fig. 3. Fog computing and IoT

Fog computing cannot be seen as an alteration for cloud computing concerning distant data storage and processing. When used for remote data processing and storage, fog computing enhances rather than replaces the cloud. When combined with the cloud, the fog nodes make it easy to build a hierarchical structure where permanent storage and global analysis are done at the cloud layer, while transit data storage and local data analysis are done at the fog nodes. At the edge of the network, close to the devices, the fog nodes are distributed unevenly. Fog computing is a part of the cloud computing paradigm that takes the cloud closer to the edge of the network [12].

The advantages of fog computing are: 1) location awareness, 2) interplay with a cloud, 3) mobility support, 4) heterogeneity, and 5) online analytics. On the other hand, security concerns [15] represent the disadvantages of fog computing.

2.4 Edge Computing

Applications send IoT data continually to a central storage unit, often housed in a cloud center. Real-time processing and low latency times are requirements for some IoT applications. It is inappropriate to use cloud computing to handle such requirements. A novel distributed IT architecture called "edge computing" is the diminution of computing applications, services, and data storage from central nodes right up to the user. In their operation, IoT devices generate a lot of data estimated at up to 500 Zettabytes of data [16]. Edge computing makes use of edge devices that have enough processing power to preprocess source data locally, act quickly, and transfer processed data or computing results to a cloud computing facility [17].

IoT experts are working to integrate edge computing and IoT paradigms to support the crucial IoT applications that call for improved quality of service (QoS) [18] (Figure 4). Real-time information on the supply radio access network (RAN) can be displayed by edge computing. In this way, network providers can increase the overall quality of experience (QoE) for Internet end users because real-time RAN will provide context-aware services [19].

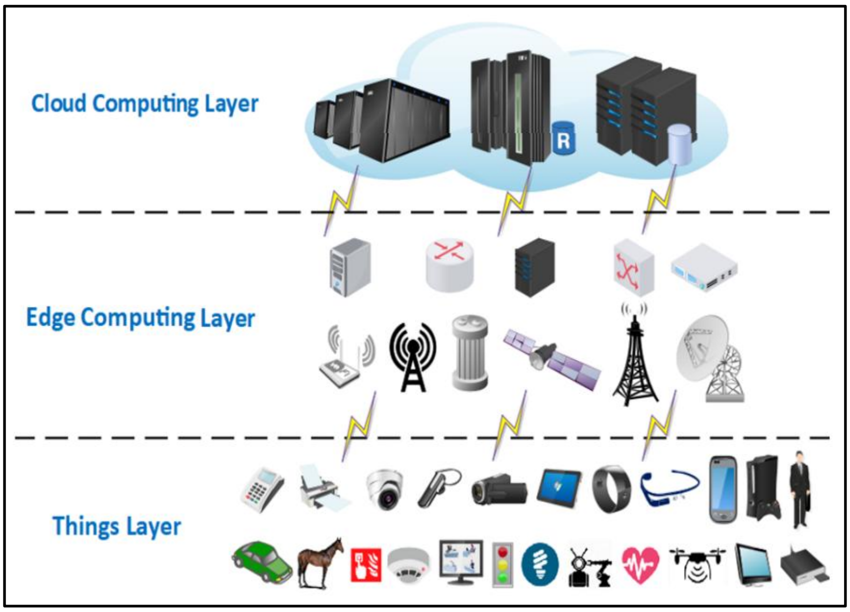

Fig. 4. Edge computing and IoT

The advantages of edge computing are: 1) efficiency, 2) cognition, 3) agility, and 4) latency solution. On the other hand, the disadvantages of edge computing are: 1) optimization, 2) security and privacy, as well as 3) resource management.

3. Literature Review

The IoT explosive growth has increased demand for sophisticated data processing technologies. Cloud computing offers scalability and flexibility, while edge computing reduces latency and improves privacy through local processing. The advantages of both are combined in hybrid architectures, such as fog computing, which maximizes bandwidth and accommodates latency-sensitive applications. By addressing the drawbacks of edge and cloud systems and enhancing IoT ecosystem efficiency, these hybrid models provide a well-rounded solution [20].

Cloud computing and IoT integration are essential for effective monitoring and management systems in medical environments. In [21], architectures that could improve hospital information systems by enabling remote monitoring were suggested. Results from experiments indicated that sophisticated algorithms could greatly enhance service performance, pointing to promising directions for future research.

Cloud computing increases flexibility and innovation by providing necessary computing resources via the Internet, but it also raises serious security and privacy issues. While the IoT facilitates smooth connectivity and data sharing between devices, its dependence on cloud infrastructure increases vulnerabilities and necessitates strong security and storage solutions. According to [22], the use of these technologies is increasing, which calls for a thorough comprehension of the effects on organizations and risk management techniques.

Cloud computing and IoT integration allow for smooth data exchange but also introduce serious security risks like illegal access and data breaches. These threats were surveyed and categorized in [23]. This work also assessed current security measures and pinpointed major obstacles to protecting cloud-based IoT architectures. Comparative evaluations of existing solutions pointed out weaknesses and offered recommendations for improving security in this changing environment.

In [24], the comparison of IoT deployment highlighted how different technological and infrastructure environments influenced each nation's strategy. Comparative studies highlighted particular opportunities and challenges by exposing variations in architectural frameworks, economic impacts, and strategic goals. This study offered important new information about how societal demands, technological advancements, and policy affect IoT developments in various settings.

The spread of IoT has improved human quality of life and system efficiency by revolutionizing data collection and communication through intelligent sensors. Important IoT communication protocols were compared in [25], with an emphasis on their adaptability to constrained networks, security features, and transport mechanisms. The study also assessed popular cloud platforms, paying particular attention to their security protocols, service offerings, and architectures.

Data transmission, storage, and security issues were addressed by combining the IoT with cloud and fog computing paradigms in [26]. For IoT applications at the network's edge, fog computing provided better real-time processing capabilities and reduced latency when compared to cloud computing. Fog's benefits in lowering latency and enhancing data accuracy were also highlighted.

Both edge and cloud computing are essential components of contemporary systems. Edge computing guarantees low latency and real-time data processing, while cloud computing is superior at managing large data and providing scalable resources. Studies demonstrate how these paradigms can work in tandem to maximize performance across a range of applications. Strategic integration was emphasized in [27], which also provided organizations with insights and future research directions.

With the help of cloud computing and M2M communication technologies, the IoT combines real-time data processing, exchange, and knowledge extraction across connected devices. Given the variety and volume of data involved, IoT systems have difficulty managing resource constraints like memory and CPU. With an emphasis on the potential of information systems and feature extraction techniques for effective IoT-data management and optimization, the review provided in [28] examined the connections between IoT and cloud environments.

In [29], the authors assessed pertinent literature using bibliometric analysis and the PRISMA method, considering co-authorship and term co-occurrence. They examined how IoT and cloud computing could be combined. Also, they emphasized the advantages, difficulties, and restrictions of doing so.

4. Discussion

A discussion of different features (i.e. definition, focus, devices, processing, scalability, security, cost, complexity, and application) of different features of IoT, cloud computing, fog computing, and edge computing is given in Table 1.

5. Conclusion

In this paper, we presented a literature review of cloud computing and IoT. First, we examined the fundamentals of cloud computing and IoT. Then, we talked about how they complement one another and what are their main differences.

IoT can greatly benefit from the abundance of resources found in the cloud. IoT applications can be built into all domains practically to the imaginable areas such as medical, manufacturing, industrial, transportation, education, etc. Cloud computing and the IoT are the next giant leap for the World Wide Web. New opportunities emerging from this amalgamation known as IoT Cloud are extending newer opportunities for business and research as well. Cloud computing and the IoT will revolutionize the whole information and communication technology sector, change the course of technological advancement, and impact the economy in the forthcoming years.

Table 1
Discussion of different features

Feature	IoT	Cloud	Fog	Edge
Definition	A group of interconnected tangible objects that contain sensors, software, and other technologies that are used for exchanging data	A network of remote servers that provide on-demand computing resources, data storage, and applications	Fog computing includes traditional cloud computing as well as dispersed computing, storing, and networking services among various end devices.	A new form of distributed IT structure that targets the extension of the actual computing platform, applications, services, and data storage to the end user
Focus	Data collection and analysis from the physical world	Data storage, processing, and application delivery	Decentralized processing and collaboration among nearby connected devices and fog nodes.	Bringing processing and storage closer to data sources for faster, more efficient, and secure applications
Devices	Sensors, actuators, smart devices, wearables	Virtual machines, containers, databases, storage systems	Micro servers, gateways, MEC platforms	Sensors, cameras, smartphones, wearables
Processing	Can occur at the edge (on the device) or in the cloud	Primarily occurs in the cloud	Processing occurs on fog nodes, which are devices located between the edge devices and the cloud	Directly on the edge device itself
Scalability	Highly scalable, with millions of devices connecting to a single cloud platform	Highly scalable, with resources dynamically allocated based on demand	More scalable than edge, ideal for pre-processing and aggregation	Highly scalable in terms of devices, but limited processing power per device
Security	Requires strong device security and end-to-end encryption	Relies on cloud provider security measures and data encryption	Multi-layered approach, addressing vulnerabilities promptly	Multi-layered approach
Cost	Can be expensive due to device costs and data transmission charges	Can be cost-effective, with pay-as-you-go pricing models	Moderate cost, moderate scalability, balanced approach	Low operational cost, high device cost, limited scalability
Complexity	Can be complex to manage and secure, especially with large deployments	Relatively simple to manage and secure, with centralized control and administration	Higher complexity than cloud due to distributed systems, resources, heterogeneity, and security	Higher complexity than cloud due to distributed systems, resources, heterogeneity, and security
Application	Industrial automation, smart cities, connected healthcare, environmental monitoring, consumer electronics	Web applications, data analytics, software development, enterprise resource planning, content delivery networks	Local analysis (video surveillance, factory maintenance, smart cities)	Instant responses (smartwatch, smart speaker, traffic lights)

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Conflicts of Interest
The author declares no conflicts of interest.

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