The Impact of the Internet of Everything on Green Cloud Computing

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Abstract. In today's world, the demand for computing power and the need for environmental protection and energy saving have made Green Cloud Computing (GCC) popular in various fields. Customers from all over the world can access processing power and resources through cloud computing. It offers excellent performance and cost savings compared to specialized HPC devices. However, cloud computing will use many data centers, resulting in considerable energy consumption and a large amount of carbon dioxide emissions. Green Cloud Computing was created to solve this problem using recycled energy and sustainable and energy-efficient methods. For Green Cloud Computing, IoE allocates energy and computing resources more reasonably. At the same time, IoE promotes the concepts and techniques of Green Cloud Computing to reduce carbon emissions further. The Internet of Everything will more deeply influence the application of Green Cloud Computing and various fields by connecting people, data, and machines. This paper provides an overview of the history of the Internet of Everything and Green Cloud Computing. The Internet of Everything is widely used and has been shown to impact Green Cloud Computing profoundly. There is great potential for developing the Internet of Everything and Green Cloud Computing in the short future and significantly promoting sustainable computing development.

Keywords: Internet of Everything (IoE) · Green Cloud Computing (GCC) · People to people (P2P) · People to machine (P2M) · Machine to machine (M2M)

1 Introduction

The Internet of Everything (IoE) is no longer a new word due to the rapid development of the internet. The internet makes it possible to connect not only people but also everything. The concept of IoE includes the Internet of Things [1]. Unlike IoT, which connects physical devices, IoE intelligently connects devices and people, processes, data, and things [2, 3], just like its name – "everything". With the concept of IoE, almost everything can be connected to each other via the internet.

The Internet of Everything provides a broader platform for the development of Green Cloud Computing. As massive data needs to be managed and analyzed, the Internet of Everything needs a large-scale computing platform as support. Cloud computing has

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the advantages of large scale, standardization, high security, and so on, which can meet the development needs of the Internet of Everything. Because of Cloud Computing, developers with innovative ideas for new Internet services no longer require significant capital outlays in hardware to deploy their service or the human expense to operate it [22]. Reducing carbon emissions by cloud computing data centers has emerged as one of the dominant research topics both in industry and academia [15]. Green cloud computing aims to reduce the negative environmental impact of cloud computing by using sustainable and energy-efficient methods. Greening cloud computing technology has become an essential aspect of an organization's design and use of cloud computing [23]. With the emergence of the Internet of Everything, energy demand has increased, and green cloud computing strategies have been adopted. In the Internet of Everything process, the concepts and methods of green cloud computing are continuously applied to reduce carbon emissions further.

This paper briefly overviews the inextricable relationship between the Internet of Everything and Green Cloud Computing. The article introduces the background of the development of the Internet of Everything and Green Cloud Computing, emphasizing the impact of the Internet of Everything on Green Cloud Computing. Finally, the article discusses the combination of IoE and Green Cloud Computing to drive growth in multiple fields.

2 Background of IoE and Green Cloud Computing

The Internet of Everything is developing based on the Internet. The Internet originated in the 1960s when the U.S. Department of Defense commissioned the development of ARPANET to research the Internet [5]. Then, the TCP/IP protocol proposed by Wynton Cerf and Robert Kahn significantly advanced the development of the Internet. In the 1980s, to share computer and network resources, the National Science Foundation established the NSFNET wide area network to make the Internet available to the entire community. The Internet of Things (IoT) [1], which connects physical devices, extends the user side to communicate at the item level after the development of the Internet.

Green Cloud computing relies on the virtualization technology that has gradually developed and has become one of the most concerning technologies in the field of computers. Table 1 provides a brief history of Green Cloud Computing in IoE content. In 2006, Eric Schmidt proposed the "Cloud Computing" concept at SES San Jose 2006. Cloud computing dates back to 1959 when Christopher Strachey published the paper "Time Sharing in Large Fast Computer" at the International Information Processing Conference and put forward the concept of virtualization [6]. In 1998, VMware was founded, and the X86 virtualization technology was introduced for the first time [9].

With the advent of fast cloud computing, new service categories are emerging. In 2006, Amazon launched its IaaS (Infrastructure as a Service) platform, AWS. Heroku introduced the first public cloud PaaS (Platform-as-a-Service) in 2009 [11]. In 2010, the open-source cloud software plan of OpenStack was launched, marking the beginning of the open-source era for cloud computing. In 2014, AWS introduced Lambda, which allowed you to run code in AWS without configuring or managing a server.

Green cloud computing has gained popularity over the last decade due to the extensive use of cloud computing [26]. With the fundamental principle of sustainable development, the notion of "green computing" first emerged in 1987, and the main aim is to lower energy usage [7]. In 2009, Liu et al. [8] presented Green Cloud, a new architecture that aims to decrease data center power consumption. Hasan *et al.* [28] adopt renewable energy virtualization technologies to solve the supply uncertainty issue in data centers. A green SLA algorithm was proposed for data centers due to the obtainability of uplifting energy and its erratic presence. In HPC, Performance and energy consumption of high performance computing (HPC) interconnection networks have a great significance in the whole supercomputer, and Zhou et al. [32] designs and implements a detailed and clock-driven HPC interconnection network simulation platform, called HPC-NetSim. Chen *et al.* [31] proposes an energy efficiency optimization method to improve performance and control power consumption in multi-computing environment by increasing computing nodes and reducing processor frequency. World leaders came together in 2015 and made a historic promise to secure the rights and well-being of everyone on a healthy, thriving planet when they adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) [33]. Goal 7 is about ensuring access to clean and affordable energy, which is key to the development of agriculture, business, communications, education, healthcare and transportation. And Green Cloud Computing is committed to Goal 7.

Table 1. Development of Green Cloud Computing

Years	Notion or Product	Stage meaning
1969.06	*Virtualization*	The earliest discussion of virtualization technology [6]
1987	*Green Computing*	the notion of "green computing" first emerged [7]
1998	*VMware*	The virtualization technology of X86 is introduced for the first time [9]
2006	*Cloud Computing*	The notion of "Cloud Computing" was proposed for the first time [10]
2006	*AWS*	The first appearance of IaaS [19]
2009	*Green Cloud*	A new architecture that aims to decrease data center power consumption [8]
2009	*Heroku* [11], *one of the first cloud platform*	The first appearance of PaaS
2010	*OpenStack* [12]	Cloud computing has begun to enter the era of open-source
2014	*Lambda*	The first appearance of FaaS

3 The Impact of IoE on Green Cloud Computing

The purpose of Green Cloud Computing (GCC) is to lessen the adverse effects of Cloud Computing (CC) on the environment by using sustainable and energy-efficient methods [7]. At the same time, Green Cloud Computing is the on-demand access to computing resources over the Internet, including applications, servers (physical and virtual), data storage, development tools, networks, etc. These resources are hosted in remote data centers managed by cloud service providers.

As shown in Fig. 1, the IoE connects spaces such as people's homes with business and mobile settings. Connections to the internet include people-to-people (P2P), machine-to-machine (M2M), and people-to-machine (P2M) systems, while all of them comprise people, data, processes, and things [1, 20].

During the study of Green Cloud Computing, as shown in Fig. 2, the Internet of Everything connects people, data, and things. In the process of green cloud computing, the systems of people-to-people (P2P), machine-to-machine (M2M), and people-to-machine (P2M) are apparent.

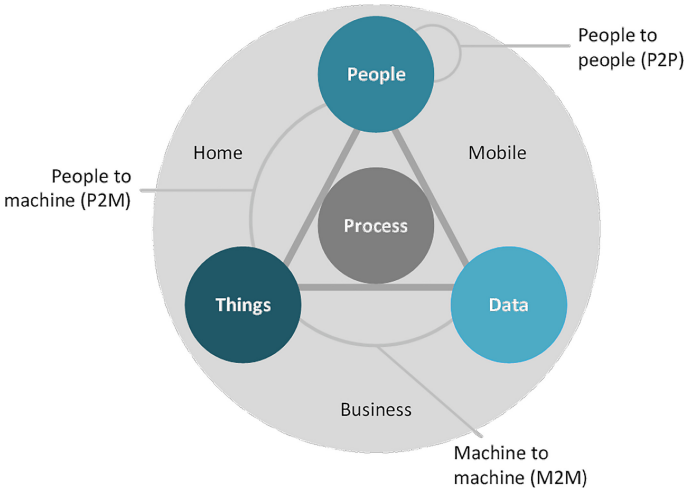

Fig. 1. The three communication channels in the IoE (See Fig. 2 in [1])

3.1 P2P in Green Cloud Computing

The People-to-People (P2P) system includes two representative interactions in Green Cloud Computing: User-to-User (U2U) and User-to-Green Broker-to-Service Provider (U2B2P). Users can achieve cooperation and services through green cloud computing. For example, teachers (User) can use cloud computing to build online teaching platforms to provide distance education services for students (User). Green Broker connects the User and Service Provider. The Green Broker functions as an intermediary of utmost

intelligence, strategically positioned within the realm of cloud infrastructure, meticulously governing and optimizing the intricate utilization of energy resources [29]. In addition to acting as an intermediary, green brokers can provide other services to users, such as data deduplication, encryption, moving data to the cloud, and data life cycle management (DLM [16]).

3.2 P2M in Green Cloud Computing

The people-to-machine (P2M) system also includes three parts, as the left-most part in Fig. 2 shows. Green Cloud Computing can provide powerful, safe, stable, and environmentally friendly cloud products to anyone who connects to the internet. Tens of millions of developers use cloud computing to promote green cloud computing, more efficient, stable, and green environmental protection. The scalable cloud process scheduler generates virtual cloud environments on schedule for high speed and consistent operation of user requests [27]. Dynamic Voltage and Frequency Scaling (DVFS) techniques [13] enable service providers to manage power consumption and server performance better, thus leading to cost savings and improved efficiency.

3.3 M2M in Green Cloud Computing

The machine-to-machine (M2M) system contains three parts, as Fig. 2 shows: Different physical machines influence each other through cloud computing. For example, the power consumption of the computing node affects the power of the cooling node. Physical machines in green cloud computing are connected through the Internet. Virtual servers can be easily transplanted between different physical servers by using virtualization technology.

4 Development Trends of Green Cloud Computing and IoE

This chapter briefly looks at the future of IoE and Green Cloud Computing and mentions how each affect the other.

There are two main trends in Green Cloud Computing. First, Cloud Computing will continue to evolve, with hybrid cloud, edge computing, and cloud-native technologies becoming mainstream. On the other hand, the energy consumption optimization of green cloud computing is becoming more and more challenging, and energy consumption optimization and resource allocation technologies are constantly developing.

4.1 Using IoE for the Future of Cloud Computing

With the deepening of the Internet of Everything (IoE), more diverse users and more cloud providers join cloud computing, which makes the ways of cloud computing interconnection more varied.

From the original single private cloud and public cloud to the rise of the hybrid cloud model, the Hybrid cloud [17] helps achieve better resource optimization and risk diversification. With the development of the Internet of Things (IoT [1]) and 5G

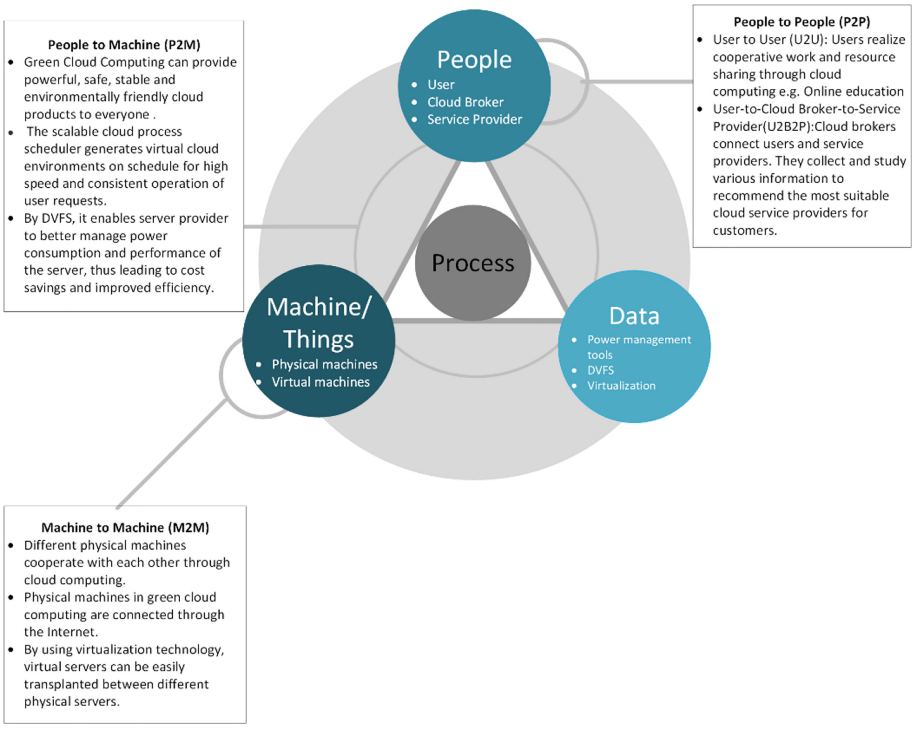

Fig. 2. P2P, P2M, and M2M connections in Green Cloud Computing

technology, data processing will extend from the cloud to edge devices [18], achieving lower latency and higher efficiency. At the same time, cloud-native technology [19] will become the mainstream model for enterprise application development, enabling faster application deployment and better scalability.

4.2 Using IoE for the Future of Green Cloud Computing.

Based on the emergence of massive data storage and hybrid cloud, more and more cloud providers join, making the cloud computing model more complex and diverse, aggravating the energy consumption optimization challenge in large-scale cloud computing data centers. Future work will concentrate on the implementation of techniques for energy efficiency in Cloud Computing and investigating the use of scheduling techniques in newly emerged fog and edge environments [17].

Effectively loading balance energy-efficient hardware and software and energy-efficient cooling can all help to make cloud computing green.

One aspect of future Green Cloud Computing is effectively balancing their cloud computing resources. Efficiently using cloud-based resources is an integral part of Green Cloud Computing. Kumar's model can help organizations to efficiently distribute their cloud-based resources, which allows for a greener cloud computing system [23].

Improving cooling efficiency is one of the most efficient ways to reduce power consumption in Cloud Computing. Cooling is a crucial energy consumer. Monitoring processor temperature and controlling the number of CRACs and air volume are helpful methods to adjust the capability of CRACs [25]. Data centers may lower their energy use and carbon impact by utilizing energy-efficient cooling methods, such as free cooling. Free cooling includes cooling the data center using outside air rather than mechanical cooling systems, which in some cases may be more energy-efficient [29].

Hardware and software that consume less energy are crucial methods for making cloud computing green. In an era where power and energy are the first-class constraints of computing systems [30], data centers may lower their energy use and carbon impact by utilizing low-power CPUs, memory architecture, and other hardware elements [29]. Software is essential for green cloud computing. Applications can improve energy efficiency and resource management.

5 Conclusion

The history of Green Cloud Computing is progressing with the development of the Internet of Everything (IoE). At the same time, the application of green cloud computing promotes the development of the Internet of Everything (IoE). The systems of People-to-People (P2P), People-to-Machine (P2M), and Machine-to-Machine (M2M) are reflected in Green Cloud Computing. From the future trends of Green Cloud Computing, some of the existing future development directions are also very much in line with the Internet of Everything (IoE). It is expected that green cloud computing will continue to focus on the energy efficiency and carbon emissions of the Internet of Everything (IoE) and provide energy-efficient and efficient services.

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