GROWING FIELD OF CLOUD COMPUTING

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Abstract:

Cloud computing has emerged as a progressive field within information and communication technologies (ICTs), introducing new challenges and opportunities for environmental protection. This technology boasts diverse applications, offering flexibility, reliability, dependability, and high performance at reasonable costs. The cloud computing revolution is reshaping contemporary networking, presenting promising forecasts for environmental defense, along with economic and technological advantages. These advancements have the potential to improve energy efficiency, reduce carbon footprints, and mitigate electronic waste, thereby transforming cloud computing into "green cloud computing." This survey provides an overview of cloud computing, summarizes recent studies and developments, and meticulously addresses environmental concerns. The aim is to offer current insights for research pertaining to green cloud computing.

Keywords: Green cloud computing; green information and communication technologies; environmental protection; sustainability

INTRODUCTION

Sustainability has become increasingly significant in the realm of software and hardware development over the past two decades, primarily due to the escalating energy consumption in the technology sector. The impact of data and communication technologies (ICTs) on the environment has been thoroughly examined across their entire life cycle to promote green and sustainable practices. These efforts aim to mitigate the adverse effects that have intensified over the last few decades and significantly contribute to improving the current state of the environment. Manufacturers are under considerable pressure to align with environmental regulations, producing products and services that minimize negative ecological impacts. According to Hilti et al., any judgment concerning the sustainable development of ICTs must consider both the advantages and disadvantages of ICTs on the environment, both presently and in the future. The allure of these technologies has often led to neglect of environmental concerns by both producers and users. However, the maturity of these technologies, coupled with pressure from international environmental bodies, has driven a shift towards environmentally compliant applications of ICTs.

There is a clear interest in monitoring and preserving the ecosystem, but challenges such as associated costs, a lack of time and interest, insufficient accountability for environmental impacts, and a lack of collaboration between departments within companies pose obstacles. Cloud computing, as a subset of ICTs, is a subject of environmental studies. Komi notes that the energy consumed by data centers in 2010 represented 1.3% of the total consumption. Recognizing the potential environmental impact of cloud computing and energy consumption, researchers at Lawrence Berkeley National Laboratory and Northwestern University developed a modeling tool called the Cloud Energy and Emissions Research Model (CLEER). Their findings suggest that the initial energy footprint of email, productivity software, and Customer Relationship Management software could be reduced by up to 87% if all business users in the US shifted to cloud computing. The mentioned modeling tool, even if not considering all variables, holds utility in promoting energy efficiency within data centers owned by Internet companies. Its potential lies in enhancing energetic transparency, empowering consumers to make informed choices about the services they select.

According to Wikipedia, cloud computing is a convergence of computing concepts where thousands of computers interconnect to provide a seamless user experience, as if accessing a single vast resource. The concept of cloud computing dates back to the early 1950s, although the term itself was not coined at that time. It was referred to as time-sharing systems during this era. From 1960 to 1990, several experts alluded to the concept of cloud computing in their writings. However, the term "dumb terminal connected to the server" was more popular than "cloud computing" during this period.

In the early 1990s, telecommunication companies began offering Virtual Private Networks (VPNs) instead of dedicated connections, which were more cost-effective. Salesforce.com, in 1999, was among the pioneers in delivering enterprise applications through a website. Amazon, around 2002, played a significant role in advancing cloud computing, particularly with the introduction of Amazon Web Services (AWS) and Elastic Compute Cloud (EC2).

Since 2009, following the rise of web 2.0, major players in the internet industry such as Yahoo and Google have also entered the cloud computing arena. The primary models in cloud computing include Service Models, comprising platform as a service, software as a service, and infrastructure as a service. The Development Models include public cloud, private cloud, community cloud, and hybrid cloud, further expanding the possibilities in cloud computing. The primary objective of cloud computing is to enhance the utilization of shared resources, but it comes with drawbacks, particularly the escalating infrastructure costs and unnecessary power consumption.

In the context of the growing concerns about global warming, the surge in power consumption and CO2 emissions has become a significant issue. Environmental organizations and initiatives such as Greenpeace, the United States' Environmental Protection Agency (EPA), and the Climate Savers Computing Initiative have contributed to raising awareness and fostering a sense of responsibility toward the environment.

The continuous and widespread adoption of cloud services, coupled with the increasing global awareness of ecological sustainability, has prompted researchers to explore concepts for an environmentally friendly and energy-efficient form of cloud computing known as "green cloud computing."

Previous studies suggest that green cloud computing can contribute to reducing energy consumption and CO2 emissions by efficiently reusing energy resources. However, it is essential to acknowledge the potential disadvantages, notably the high infrastructure costs and unnecessary power consumption associated with implementing green cloud computing solutions. Balancing the advantages and disadvantages is crucial for realizing the environmental benefits while addressing the economic and operational challenges of green cloud computing.

resources. It relies on virtualization technologies to create a robust and flexible computing environment accessible through cloud data centers. The central idea behind cloud computing is to provide dynamic, high-capacity computing capabilities and access to sophisticated applications and data storage without the need for additional physical computing resources.

This paradigm has gained significant attention and adoption, particularly among organizations, due to the potential cost savings achieved by reducing investments in hardware and software. Key concepts associated with cloud computing include:

1. Service-Oriented Architecture (SOA): A design approach where software components are designed to be reusable services that can be orchestrated to meet specific business needs.

2. Microservice Architecture: A design pattern in which an application is composed of small, independent services that communicate with each other to form a complete application.

3. Distributed Computing: The use of multiple computer systems to work together on a task, often in parallel, improving performance and reliability.

4. Parallel Computing: Simultaneous processing of data using multiple processors to achieve faster computation.

5. Grid Computing: Connecting computers to work together on a task, often used for complex scientific and technical problems.

6. Virtualization: Creating a virtual (rather than actual) version of something, such as a server, storage device, or network resources, to improve efficiency and flexibility.

7. Containerization: Packaging applications and their dependencies together in a standardized unit, known as a container, for easy deployment and scalability.

Cloud computing services are characterized by their dynamic nature, and according to Feininger, the key attributes defining this novel ICT provisioning model are ubiquity, service-centricity, scalability, resource pooling, and self-service. The concept is primarily defined by its features and involves the integration of existing technologies and models to optimize the use of both physical and logical resources. In the realm of cloud computing, resources are treated as services and are made available to users based on their specific requirements. Three key service models categorize these resources: IaaS (Infrastructure as a Service), PaaS (Platform as a Service), and SaaS (Software as a Service). Each model caters to different stakeholders in the computing ecosystem.

1. IaaS (Infrastructure as a Service): This model provides virtualized computing infrastructure over the internet. It offers virtual machines, storage, and networking resources. IaaS is suitable for individual software vendors and developers who need a flexible and scalable infrastructure to build and deploy applications.

2. PaaS (Platform as a Service): PaaS goes a step further, offering a platform that includes not only infrastructure but also tools and services to develop, test, and deploy applications. It is designed for developers and focuses on simplifying the development process.

3. SaaS (Software as a Service): SaaS delivers software applications over the internet on a subscription basis. End users access these applications through a web browser without worrying about the underlying infrastructure. This model is tailored for end users seeking ready-to-use software solutions.

To further categorize cloud computing environments, a typology based on the degree of availability is often employed. This results in four main deployment models:

1. Private Cloud: Resources are used exclusively by a single organization. This model provides more control and privacy but may have higher costs.

2. Public Cloud: Resources are shared among multiple organizations, and services are delivered over the internet. It offers cost-effective solutions but may raise security concerns.

3. Hybrid Cloud: Combines elements of both private and public clouds, allowing data and applications to be shared between them. This model provides flexibility and optimization of existing infrastructure.

4. Community Cloud: Shared by several organizations with common concerns (e.g., regulatory requirements, security standards). It offers a balance between public and private cloud models.

This typology, illustrated in Figure 1, helps in understanding and classifying different cloud computing environments based on their availability and deployment characteristics.

Green Cloud Computing in Non- Academic Studies

In non-academic studies, the focus on green cloud computing is evident in various activities aimed at performing tasks with fewer resources and lower energy consumption. This efficiency is beneficial for both users and green data centers. The enhanced resource efficiency contributes to a reduction in energy consumption and a more sustainable approach to computing. Despite the reduction in hardware requirements, the demand for cloud computing services is predicted to continue increasing.

The study suggests that these activities lead to significant environmental benefits. An estimated annual carbon reduction of 85.7 million metric tons, equivalent to 50% of CO_2 emissions, is projected. The decrease in energy consumption and hardware requirements not only results in reduced CO_2 emissions but also contributes to a decrease in electronic waste (e-waste).

Major cloud companies, including Apple, Facebook, Google, Amazon, Microsoft, IBM, Salesforce, among others, have made commitments to use only renewable energy in their data centers. The data presented in Table 3, collected by Greenpeace in 2012 and 2016, provides information about the energy sources employed by some of the large cloud computing providers.

The study emphasizes the importance of renewable energy in reducing the carbon footprint and meeting climate legislation requirements. Companies that have committed to using clean energy in their data centers are making progress in this direction. The power efficiency of servers is identified as a crucial factor in reducing energy consumption. Contrary to initial expectations, hardware requirements have experienced slower growth, indicating the positive impact of energy-efficient servers.

While many opinions favor the growth of the cloud computing phenomenon, not all viewpoints align with this perspective. It suggests that considering the environmental implications, compliance with carbon limits, and climate legislation, green IT is not just a choice from an operations standpoint but a necessity. This highlights the dual benefit of energy-efficient computing in both operational and compliance aspects. The study published by Greenpeace highlighted a potential increase in CO_2 emissions and global warming associated with the expansion of cloud computing. While no data centers have been proven fully green, there is a notable improvement in their environmental impact compared to historical records. The study suggests that cloud computing has the potential to contribute to ecological defense by reducing e-waste. By incorporating eco-friendly aspects, cloud computing may lead to a decrease in equipment usage and associated negative effects, particularly related to e-waste and CO_2 emissions.

It is crucial to note that the quantity of e-waste has been on the rise, reaching 49 million tons in 2012. Urban solid waste, including e-waste, represents over 5%, indicating a 2.4% increase from 2014. However, specific information regarding the amount of e-waste generated by cloud computing is not readily available.

Non-academic publications, as mentioned in the study, identify, analyze, and discuss the real or potential contributions of cloud computing to environmental protection. The benefits and drawbacks of cloud computing in this context are explored, recognizing that information about the actual impacts of cloud computing on the environment is limited. This underscores the need for further research and comprehensive data to fully understand the environmental implications of cloud computing.

Advantages

1) Reduces paper waste

Indeed, the shift to cloud computing has significantly transformed traditional office practices, particularly in the realm of document management. For many years, paper has been a fundamental aspect of office operations, but the advent of the cloud has brought about notable changes. The cloud has substantially diminished the need to generate physical documents, as files and documents can now be stored and shared digitally within the cloud infrastructure.

The move to digital document storage in the cloud offers several advantages:

1. Improved Energy Efficiency: Traditional paper-based document storage requires physical space and incurs energy costs associated with maintaining files, cabinets, and printing equipment. In contrast, cloud storage is more energy efficient as it eliminates the need for physical storage space, reducing the environmental impact.

2. Enhanced Security: Storing documents in the cloud enhances security. Digital files can be encrypted, access-controlled, and backed up regularly on secure servers. This mitigates the risk of physical damage or loss, and duplicates can be easily created on backup servers, providing a robust disaster recovery solution.

3. Accessibility and Collaboration: Cloud-based document storage allows for easy access to files from anywhere with an internet connection. This facilitates remote work and collaboration among team members, promoting flexibility and productivity.

4. Cost Savings: The cloud eliminates the need for extensive physical storage infrastructure, reducing costs associated with paper, printing, and physical storage space. It also streamlines document management processes, saving time and resources.

5. Environmental Impact: The transition to digital document storage in the cloud contributes to environmental sustainability by reducing paper consumption, decreasing the demand for physical storage space, and minimizing the carbon footprint associated with paper production and disposal.

Overall, the adoption of cloud-based document storage represents a significant step towards a more efficient, secure, and environmentally friendly approach to managing information in modern offices.

2) Reduces energy consumption :

1.Efficient Processes: Cloud service providers leverage the efficiency gained from hosting numerous servers in their facilities. This bulk processing capability allows for streamlined and efficient operations.

2.Virtualization Techniques: The use of virtualization techniques, such as workload migration between machines and geographically distributed data centers, enhances the overall efficiency of cloud services. This allows workloads to be concentrated in environmentally friendly or "green" cloud data centers.

3.Capacity Planning: To address environmental concerns, capacity planning needs to consider thermal aspects, optimizing heat recirculation, and possibly concentrating data centers in areas with abundant natural cooling resources.

4.Non-Technical Aspects: The term "non-technical aspects" refers to ethical considerations, adherence to internal and international environmental regulations, and adherence to organizational policies. The location of data centers and their impact on the local environment can be influenced by non-technical factors.

5.Cost of Green Cloud Computing: The cost associated with implementing green cloud computing, including the use of renewable energy sources, is highlighted as a non-technical challenge. The intermittency of renewable energy sources poses a specific challenge for cloud computing providers.

6.SLAs (Service Level Agreements) Compliance: Ensuring that service level agreements' requirements are met requires a strategic approach to managing the intermittent nature of renewable energy sources. A combination of energy sources is suggested to complement each other and maintain uninterrupted cloud service operations.

7. Government Incentives: Taking advantage of government incentives is highlighted as a benefit of adopting green cloud computing. Various incentives, ranging from tax benefits to rebates, are offered by both local and federal agencies to encourage corporate energy efficiency. This can result in additional cost savings for enterprises adopting green computing practices.

Disadvantages:

1.High Implementation Cost: One of the disadvantages mentioned is the high initial investment required for green computing. Particularly for medium-sized and small organizations, the perceived high implementation cost may act as a barrier to adoption. This indicates that green computing is not yet universally affordable.

2.Evolving Technology: The evolving nature of green cloud computing technology is identified as a potential challenge. As the technology develops, it might be challenging for everyone to adapt immediately. This highlights the need for continuous learning and adaptation to stay current with advancements in green computing.

Applications:

1.Management of Energy in Data Centers: Green cloud computing is widely used in managing energy consumption in data centers. This involves optimizing the use of resources to reduce energy consumption and improve efficiency.

2.Green Wireless Network: Green computing principles are applied to wireless networks to enhance energy efficiency and reduce environmental impact.

3.Green Parallel Computing with Big Data Network: Green computing practices are implemented in parallel computing environments, especially those dealing with big data networks, to optimize resource utilization and minimize energy consumption.

4.Green Computing with an Algorithm: Green computing is applied in algorithm design to create energy-efficient algorithms, contributing to overall sustainability.

Future Scope:

1.Importance of Green ICT: Green ICT is emphasized as crucial, serving as both a solution and a challenge for environmental issues. Green cloud computing is identified as a significant component of this field, suggesting a continued focus on sustainability in information and communication technologies.

2.Research Focus: The future scope includes ongoing research efforts, particularly in areas such as cloud computing security and quality of services. The quality of services mentioned involves customer satisfaction as well as meeting environmental protection requirements.

3.Software Design for Green Cloud Computing: The importance of software design for green cloud computing is highlighted. Efficient resource management and improved communication between software components are seen as ways to enhance the environmental sustainability of cloud computing.

In summary, the text discusses the advantages, disadvantages, applications, and future scope of green cloud computing, emphasizing its potential for cost savings, the challenges of implementation cost and evolving technology, and its applications in various organizational areas. The future scope includes ongoing research and a focus on software design for improved efficiency and sustainability.

1.Virtualization Techniques: The text suggests that virtualization techniques can be enhanced through the migration of workloads between machines, including virtual machine (VM) migration between geographically distributed data centers. This optimization allows for better resource utilization and efficiency.

2.Concentration of Workloads: There is a recommendation to concentrate workloads in green cloud data centers. Green data centers are those designed with a focus on energy efficiency and environmental sustainability.

3.Capacity Schedule: To address the concentration of workloads and thermal aspects, a capacity schedule needs to be performed. This involves planning and scheduling the allocation of resources based on thermal considerations to optimize energy consumption.

4.Heat Recirculation Improvement: Improving heat recirculation is suggested as a way to enhance the overall efficiency of data centers. Efficient heat management contributes to reduced energy consumption and improved environmental sustainability.

5.Building Data Centers in Areas with Free Preservation Resources: A non-technical solution proposed is to build data centers in areas with readily available preservation resources. This could include locations with natural cooling mechanisms, reducing the need for energy-intensive cooling systems.

6.Non-Technical Facets: The term "non-technical facets" refers to ethical considerations, adherence to internal and international environmental regulations, and adherence to the organization's internal policies and methods. These aspects are crucial in ensuring that cloud computing practices align with environmental and ethical standards.

7.Cost of Green Cloud Computing: The passage highlights the non-technical issue of the cost associated with green cloud computing. While environmentally friendly practices are desirable, the financial implications of implementing green solutions need to be considered.

8.Use of Renewable Energy: The use of renewable energy is mentioned as a non-technical issue. While utilizing renewable energy sources is environmentally friendly, the intermittency of such sources poses challenges that need to be addressed.

9.SLAs (Service Level Agreements) Compliance: To ensure that Service Level Agreements (SLAs) requirements are met, the passage suggests the importance of using a combination of energy sources that complement each other. This helps in maintaining consistent and reliable cloud computing operations.

Energy Efficiency Benefits: The most advertised benefits of cloud computing are related to energy efficiency. To comply with environmental regulations, cloud service providers are encouraged to minimize the consumption of energy from non-renewable sources and transition to renewable energy consumption.

Challenges in Achieving Clean Energy Usage: Studies reveal that while the push for cleaner energy usage is high, the index of clean energy usage remains significant, surpassing the energy obtained from non-renewable sources. This indicates a positive trend towards environmentally friendly practices.

Importance of Renewable Energy Consumption: The conclusion underscores the importance of increasing the consumption of energy from renewable sources, as this can contribute to lower carbon dioxide (CO_2) emissions. However, it acknowledges that achieving a significant reduction in carbon emissions may be challenging, given current circumstances.

Unmet Expectations of Environmental Organizations: The conclusion notes that, as of now, the reduction in carbon emissions may not meet the expectations of environmental organizations. This suggests a need for further efforts and advancements to align cloud computing practices more closely with environmental protection goals.

Conclusion

In summary, the conclusion reflects on the contributions and challenges of cloud computing in the context of environmental protection. It acknowledges the strides made in energy efficiency and emphasizes the importance of transitioning to renewable energy sources for a more sustainable future. However, it also recognizes that certain expectations regarding carbon emission reductions may not be fully realized at present.

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