Recent Trends in Green Cloud Computing

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Abstract Cloud computing is a ubiquitous technology which is spreading its roots in every sphere of modern computing. The benefits of these services are top-notch, but the data centers that power these services consume a huge amount of energy and pose serious threats to the environment due to the increase in carbon footprint. This stems the need to shift to green cloud computing, a crucial area of research these days. Green cloud computing provides a methodology for energy management, recycling, efficient cooling, load balancing, and virtualization of servers. We have reviewed potential domains to tackle the problems that the growth of cloud computing brings along, including underutilized resources like traditional DBMS servers and high energy consumption by processors, servers, and cooling infrastructure. Along with the advantages, we have mentioned some of the disadvantages of the techniques as well. However, these disadvantages are not a major concern for the large-scale implementation of these methods. Once implemented, they are bound to alleviate the problem of hefty energy consumption and growing carbon footprint of the cloud data centers. We have also discussed various parameters which can be used to compute the power consumption by the data centers and also to quantify the green energy coefficient of the cloud services.

Keywords Cloud computing · Data center · Energy efficiency · Green cloud computing · Sustainable computing · Reducing energy consumption

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1 Introduction

Cloud computing, a rapidly growing Internet based technology, is defined as the "On Demand" service which allows the sharing of resources and handling of data over internet rather than on local computers. As stated by the National Institute of Standards and Technology [1], "Cloud computing is a model for providing suitable, cost effective and energy efficient network access to the shared system resources which can be rapidly delivered with least management effort or client and service provider interaction." The cloud technology encompasses three main services including Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS).

Cloud computing services offer surplus of advantages which provides the clients an edge over the conventional computing. Some of them are little management toil, less focus on infrastructure, faster and cost-effective application development facilities, scaling the services according to the user requirement. It also provides easy access to services which are readily available over the internet round the clock. It reduces the total cost of ownership because instead of buying and managing dedicated on-premise infrastructure, the user can avail the cloud services, conveniently on-demand. Moreover, cloud services provide security and allow the users to create backup of their data.

As a result of these benefits, various large scales as well as small scale enterprises have largely shifted to cloud computing in the past few years. Forrester Research made an estimate that cloud computing services expenditure will increase from $40.7 billion in 2011 to $236 billion in 2020 [2].

The rising deployment of cloud computing has extremely increased the amount of energy spent at data centers used for managing and distributing large chunks of data. The vast network of data centers utilizes colossal amount of electricity for running servers, processors, web peripherals, and for cooling down the heat produced by processor chips. According to United States Data Center Energy Usage Report, the overall power usage by US data centers in 2014 was approximately 70 billion kilowatt-hours which is equivalent to the amount of energy utilized by 6.4 million American homes in 2014 and is an increase of 4% from 2010 to 2014 [3]. The increasing energy usage in data centers is not only a threat to the environment, but also leads to inflated energy expenses. The multinational companies like Google, Amazon, Microsoft and Yahoo contribute half (50%) of the three-year entire cost incurred by data centers to power consumption [4].

The massive power consumption by data centers releases excessive carbon gases which are detrimental for the environment. The carbon emissions by data centers contributed to the 60% of global greenhouse gas emissions in 2011 [5]. The CO_2 emissions increase the carbon footprint which affects the global climate, increases pollution, leads to global warming and has various health impacts. If the carbon footprint goes on increasing unchecked, it will have calamitous effects on the environment.

These factors make it necessary to implement Green Cloud Computing to reduce carbon dissipation and save energy. Though some companies have taken steps to resolve the issue but still further steps need to be taken to make IT sector environment friendly on a larger scale. The increasing carbon footprint arises alarm which makes it necessary to give priority to green cloud computing and discover varied methodologies to implement it.

The paper is structured as follows: we examine the existing work done in this field under the Sect. 2. Under the Sect. 3, we discuss about various parameters which can be used for measuring power utilization by data centers. In Sect. 4, we present various potential domains that can foster green cloud computing. We discuss the future work in Sect. 5 followed by the conclusion in Sect. 6.

2 Related Work

The increased demand of cloud services among the clients has led to an increase in the data center's energy consumption and carbon emission. This has made green cloud computing trending and popular topic for research. A variety of power conserving approaches have been proposed like turning the computers off or in Sleep or Hibernate mode when not in use, using LCD monitors that use less energy, recycling the waste from old computers, using equipment with energy star label, integrated memory controller, using techniques like quad core designs which increases performance per watt [6].

Apart from these, virtualization, a cost effective and energy efficient characteristic of cloud computing, enables the processing of numerous requests and managing data by creating multiple virtual environments on a single computer system. Kaur et al. [7] discuss in their paper how virtualization reduces the hardware costs and leads to less energy utilization through VM migration and reducing CPU idle time.

Furthermore, various algorithms have been proposed to optimize the task scheduling and resource allocation strategies on cloud computing environments. Improved Differential Evolution Algorithm (IDEA) [8] is one such example. It is a combination of two algorithms namely Differential Evolution Algorithm (DEA) and the Taguchi method. The DEA algorithm has a robust exploration capability, whereas the Taguchi method provides it an excellent exploitation capability, thus making IDEA algorithm a balanced combination of exploration and exploitation capabilities. The paper [8] showed that IDEA algorithm can significantly improve the resource allocation and task scheduling process, thus making an optimum use of the server's power consumption.

Zhao et al. [9] implemented another solution to decrease the data centers energy consumption by improving energy proportionality, a relationship between amount of power consumed and performance of computer, through dynamic provisioning and CPU power scaling. Dynamic provisioning uses methods like Wake-On-LAN and VM migration that help to remotely turn on/off the servers. However, these approaches are less effective as the chances to go into sleep mode are less and waking up the servers and VM migration induce extra costs. CPU power scaling makes use of Dynamic Voltage/Frequency Scaling (DVFS) which lowers CPU frequency as the work load drops to maximize energy conservation. But, this technique doesn't deliver adequate results because even if CPU energy utilization is proportionate with system load, other peripherals like motherboard, storage devices, and disk utilize the same amount of power.

Load balancing is one of the key components for distributing workload across different nodes to prevent overburdening of a single node. Kansal et al. [10] discussed the various current load balancing approaches and then provided a comparison based on different metrics used in those techniques like resource utilization, throughput, performance etc. They also examined these methods according to the amount of energy utilization and carbon release. Also, Jayant Baliga et al. performed inclusive analysis of energy utilization of public as well as private cloud and of the three services of cloud. They analyzed the energy usage in transport, storage, processing and showed how cloud computing can employ energy efficient techniques. Also, according to the paper, cloud computing can sometimes make use of more energy than traditional computing [11].

3 Parameters to Measure Data Center Power Consumption

There are several parameters that act as a metric and can be used to quantify the power consumption of the data centers. These parameters also help us to determine the sustainability as well as the green energy coefficient of the data centers. The five most prominent parameters are discussed below:

Power Usage Effectiveness (PUE) [12] [13]. PUE was presented in 2006 and advanced by the Green Grid in 2007. PUE is the ratio of the total power consumed by the data center to that of the power consumed only by its computing infrastructure. A PUE value approaching 1.0 means approximately all the energy consumed is utilized for computing.

$$\text{PUE} = (\text{Total Facility Power})/(\text{IT Equipment Power}) \tag{1}$$

Data Center Energy Productivity (DCeP) [14]. DCeP evaluates the 'valuable work' that a data center produces in view of the measure of energy it expends. Most intriguing is that DCeP permits each data center to characterize "valuable work" as it applies to its own business.

$$\text{DCeP} = (\text{Useful Work Produced})/\left(\text{T}_{\text{power}}\right) \tag{2}$$

Energy Reuse Factor (ERF) [15]. The ERF value of a data center indicates the amount of energy which is re-used for operations concentrated outside of a data center. The primary purpose of ERF parameter is to boost the reuse of energy for some other operations instead of simply its dismissal. The value of ERF lies between

0.0 and 1.0. A value to approaching 0 indicates that no or minimal energy is reused whereas a value closer to 1 signifies that most of the energy is reused for some operations outside of the data center.

$$\text{ERF} = (\text{Energy Reused})/(\text{Total Facility Power}) \quad (3)$$

Green Energy Coefficient (GEC) [15]. GEC parameter allows an organization to measure the amount of renewable energy used by its data center as part of the total energy consumed. Green energy sources can be termed as any type of energy that is renewable and which gets replenished naturally over time. The GEC estimation of Energy devoured is measured in kWh. GEC has a maximum value of 1.0, which would indicate that approximately all the energy used by the data center is green.

$$\text{GEC} = (\text{Green Energy Consumed})/(\text{Total Energy Consumed}) \quad (4)$$

Carbon Usage Effectiveness (CUE) [15]. CUE parameter can be used to evaluate the total emanations of the various Greenhouse Gases like Carbon dioxide, Methane, Chlorofluorocarbons etc. from the data center with respect to its total IT energy consumption. The perfect value of CUE is 0.0, demonstrating that no carbon usage is related with the data center's operations. The unit of CUE is Kg CO_2 eq/kWh.

$$\text{CUE} = (\text{Total } CO_2 \text{ Emission by the Data Center})/(\text{Total Facility Power}) \quad (5)$$

4 Potential Domains Fostering Green Cloud Computing

To the extent of our knowledge, energy consumption by the data centers majorly falls under two categories: energy consumed by IT equipments like network, storage, and servers and by infrastructure requirements like cooling. As per the study by the Infotech group shown in Fig. 1, a substantial amount of energy is utilized by the cooling infrastructure, followed by the server and storage requirements.

Therefore, the below-mentioned methods, that we have proposed, tackle both these major concerns.

4.1 Shifting Datacenter Workload on Microservers

Low-power embedded microservers are more energy efficient alternatives to the conventional servers and can make data center infrastructure more environment friendly in the long run. These low energy substitutes depend on Intel low power central processing units (CPUs). They can be more productive than larger monolithic systems, given the right workloads. Large clusters of these microservers powering the data center workloads can considerably improve work done per joule, thus, achieving

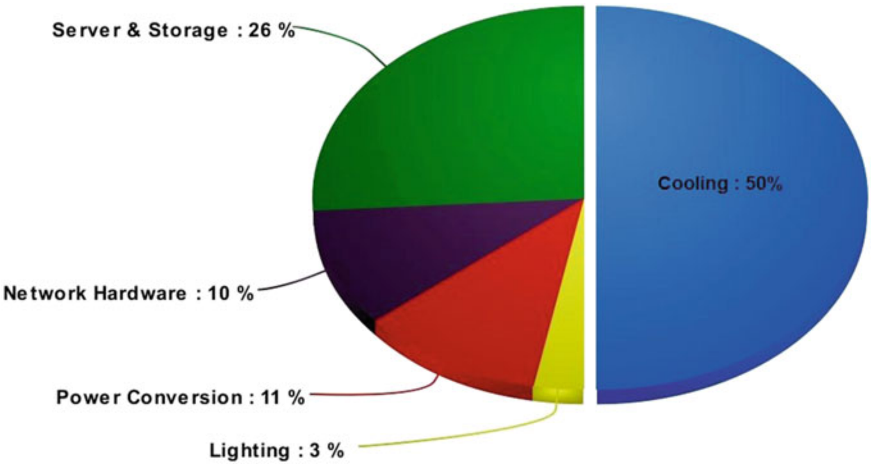

Fig. 1 Power consumption breakdown of a datacenter [16]

higher energy efficiency. Often, microservers are wrongly attributed with degraded performance. However, large swarm of these microservers can provide near-native performance of conventional servers, especially during non-peak hours [17]. Shifting data center workloads on microservers, therefore, is a viable option, particularly for managing huge chunks of archived data which is infrequently accessed.

Further, there are an abundance of microservers available in the form of defective mobile phones. This is especially true in India, which is one of the largest Smartphone markets in the world. The processors of defective mobile phones can be utilized in making large clusters of microservers. These clusters can be used to manage the data center workloads. This step will not only reap the aforementioned advantages of the microservers, but will also help towards managing piles of defective smartphones, which currently, are a threat to the environment.

4.2 Improving Datacenter Design

Uninterrupted functioning of cloud services makes cooling mechanisms to work endlessly. It causes cooling to absorb most part of the data centers overall energy. Therefore, effective methods need to be employed to cut cooling expenses by using efficient cooling methods or by decreasing the heat released. The locations of data centers can play a major role in amount of heat released and in the activity of cooling. The data centers can be shifted to geographical areas with abundant renewable sources of energy which can be utilized for cooling. Alternatively, the data centers can be moved to colder regions for downsizing the cooling costs. Moreover, instead of dissipating the extra heat produced into the environment, it can be deployed to maintain room temperature for data centers at regions with negative climates like the polar regions. Besides, the orientation and structure of data centers racks can also improve the cooling process up to a fair amount. Increasing the height of data centers ceiling and presence of proper ventilation system in the data centers can also help in decreasing the cooling costs. All these methods can help to make the cooling process cost-effective.

4.3 Utilizing a Combination of Wimpy and Traditional Servers

Traditional DBMS servers in the data centers are largely energy-inefficient due to the fact that they waste a lot of energy while underutilized. These traditional high end servers do not support flexibilities to scale down when workload is low. A lot of energy can be saved if some part of the Data Center Workload, preferably those which require only database accessing, is shifted to clusters of small (wimpy) servers, where the number of nodes forming the cluster can dynamically increase or decrease as per the workload. Although, these wimpy servers have challenges of their own, they are excellent for database accessing applications.

Using wimpy servers in data centers also foster the concept of microservices, which is an architecture in which various functionalities of an application are loosely coupled independent services that communicate with each other to deliver the business goals. Due to a surfeit of benefits like independent and expedite production and easy updating of application components without affecting other microservices, businesses have started converting their monolithic applications into blocks of microservices. To improve the fault tolerance of systems, replicas of these microservices should ideally run on different servers. So, running huge number of microservices (sometimes thousands) over traditional servers hampers the energy-efficiency as well as increases the overall infrastructure cost to a great extent. Essentially, using wimpy servers, especially for microservices, is helpful both for the environment and the cloud providers.

4.4 Increasing Transparency

Higher transparency regarding carbon and energy footprint among data companies will provide right statistics and help to tackle the problem of high carbon emissions and energy consumption better. After the plea was made by GreenPeace [18], various multinational companies like Google, Facebook and Apple became crystal clear about their energy and carbon footprint and also decided to go 100% renewable in coming years. However, there are other companies who remain ambiguous about their data. These data center operators should break the silence as increasing transparency will help to take better measures to curb the impending danger. It will also increase cooperation in the IT sector. The governments of various countries should also take measures to address the increasing carbon footprint problem by setting transparency standards and enforcing environment related laws. A governing committee or a consortium can also be founded to oversee the problem of transparency and keep in check the increasing power consumption by data centers. Increasing transparency seems an insubstantial solution but any measure in this field, however small, can pave the way for an environment healthy IT sector.

The suggested methods can be used to resolve the problem and foster the implementation of green cloud computing. These practices should be executed on a large scale to get the desired results.

5 Future Work

There are several lines of future work arising from this research paper that can be pursued. We have discussed various methods that can be implemented to make cloud services greener. Shifting to microservers can pose a problem when the workload is very high. Thus, the capability of microservers to handle greater traffic is an area of future scope. Moreover, new methods can be explored so that the cost of revamping the existing infrastructure to accommodate low power embedded micro servers is minimized.

Also, there exists a trade-off between performance and energy utilization while using Wimpy Servers. One such disadvantage of using Wimpy servers is that clusters suffer from "friction losses" and thus they may not be able to quickly adapt to changing workload environments, unlike brawny servers which deliver performance instantaneously. So, further research can be done to devise algorithms which can enhance the adaptability of wimpy servers to dynamic workload, reduce the performance lag and provide a mechanism which allows improved communication between different clusters of wimpy servers even when the workload increases substantially.

Furthermore, an effective cooling method is to find proper balance between turning off the idle servers (Power Management) and minimizing the heat generation (Thermal Management). Power management techniques focus on turning off idle servers to save power which highly increase the temperature of busy servers, consequently, increasing the amount of cooling. More research can be conducted on this balancing technique which can be a significant solution to the problem of cooling.

These areas of improvements are very crucial lines of future research work, which can make the proposed methods an optimal solution for green cloud computing. All these methods can be studied and tested extensively at a larger scale to eliminate the slight performance lag, keeping the power consumption in check.

6 Conclusion

Evidently, cloud computing is a ground-breaking advancement in the field of computer science but it poses a great threat to the environment. This raises the concern and makes it obligatory to shift to green cloud computing. This paper demonstrates deployable techniques for sharpening the energy performance of cloud computing service providers. We explored the existing work done in the field of green cloud. We discussed various parameters for evaluating power intake of data centers. We also proposed different solutions for decreasing energy utilization and carbon emanation of these data centers. The proposed methods should be adopted on a larger scale not only by giant technical companies but also by small service providers. Measures should be taken to make IT sector more ecofriendly by regulating the inflating energy utilization and CO_2 emissions. It has become the need of the hour to shift to green cloud computing to modulate the expanding danger.

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