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Green Cloud Computing: A Review on Adoption of Green-Computing attributes and Vendor Specific Implementations

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Abstract

With cloud computing emerging as a trending topic, it has been a major point of discussion for the last few years. In regards to technological advancements, the associated shortcomings like environmental footprint caused by them also become an affair of high significance. Cloud computing itself is a much greener alternative to individual data centers with lesser number of servers being used and cloud data centers being far more efficient than those of traditional thereby reducing the carbon impact. Nonetheless, it cannot be neglected the fact that the data centers utilized by the cloud vendors are still a major source of carbon emissions due to the dirty energy usage. Therefore, the discussion of the paper is based on how green the foremost cloud providers are and the implementations of green IT attributes in the cloud infrastructure.

Keywords: *Cloud Computing, Green Cloud Computing, SaaS, PaaS, IaaS, Energy Efficiency, Power Management, Virtualization, Data Centre, Resource Management, Virtual Machine(VM)*

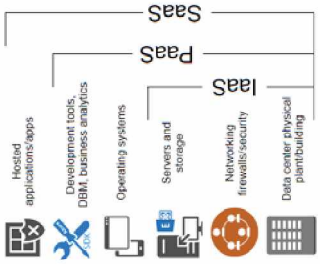
1. Introduction

Millions of mobile and internet users share photos and documents through some applications which are supportive for the critical operations of personal or business work. For this kind of operations, it is very important to have a platform which provides accelerated access to flexible and low cost IT resources. In order to provide this platform, the novel service model called cloud computing has been introduced to the world. According to Taroub Ahmed Mustafa, cloud computing accommodates an easy way to access an extensive set of application services, databases, storage and servers over the internet. Cloud services platform provides the elasticity and rapid access for flexible cost by only paying for what the user uses. Data and services are enduring in common, scalable resource pools which are dynamically expandable, generally virtualized in a cloud computing architecture. And those data and services are available for any verified device through the internet [1]**.** Google Cloud Platform, Amazon Web Services, IBM Cloud, Oracle Cloud, Microsoft Azure, Adobe, VMware, Rackspace and Red Hat are some of distinguished cloud service providers and those providers charge their customers for consuming the services according to the usage.

Another way of explaining cloud computing is, explaining the development models of cloud computing which can be described as a computing methodology that involves resource, instead of arranging the personal machine to administrate the request and the demanded applications of the user. Followings are development models of cloud:

- **Public cloud**: This will be available for any organization by allowing users to deploy and build services in the cloud environment.
- **Private cloud**: Generally, this cloud is available, maintained, controlled and deployed for a particular organization.
- **Community cloud**: Allows the users of number of specific organizations with shared concerns.
- **Hybrid cloud**: This can be a grouping of any other types of clouds (private, public or community), which have the capability over the interfaces to move and allow data or applications between more than one cloud.

Cloud computing is composed of three basic types of services as shown in the Figure 1.



- **Infrastructure as a service (IaaS)**: In this case the vendor offers access for resources like networking, storage and servers for the users by providing their own applications and platform within the infrastructure. So as a replacement for buying hardware, users can pay for IaaS on demand and there is no any single possibility even for a single point of failure. This saves money and time. This service provided by the vendors' like Microsoft Azure, Amazon Web Services (AWS), Cisco Metapod, and Rackspace.
- **Platform as a Service (PaaS)**: Here the third-party provider distributes software tools and hardware for the customers over the Internet. This third-party provider has hosted the software and hardware on his own infrastructure, so that user can proceed with the complete development and deployment environment in the cloud. PaaS includes business intelligence (BI) services, infrastructure networking, development tools, database management systems, middleware and more. PaaS provided by Windows Azure, AWS Elastic Beanstalk and Google App Engine.
- **Software as a Service (SaaS)**: This is a main service type of cloud computing where hosts applications, and makes them available to customers over the Internet by a third-party provider. Since the user or the organization does not need to install and run applications on their personal data centers or in their computers. This reduces the expenditure of purchasing hardware, software licensing, maintenance cost, cost for installation and support. Dropbox, Google Apps and Cisco WebEx are some real world examples for SaaS.

Nowadays larger organizations like Google and Facebook, have to cater millions of services to users at the same time which requires number of data centers. Unlike traditional datacenters, with the cloud these larger organizations require only fewer servers which are more power efficient and reduce the carbon influence on the organizations datacenters. Environmental protection agency has declared that "datacenters now account for 1.5% of all electricity consumption in the U.S. and by 2020, carbon emissions will have quadrupled to 680 million tons per year". Even though the cloud is a greener solution compared to the traditional data centers, with the number of users and the user requirements rapidly increasing, the cloud becomes a major cause of carbon emissions.

In the modern world the accumulating progress of computational demand and data storage, cloud computing has become a comprehensive area for researches. Because of these enhancements in the technology, the subsequent step should be the establishment of environmentally-safe, energy efficient and cost effective solutions. IT resources consume a lot of energy and power. Because of that, the global climate changes such as increase of CO2 emission and energy shortages can be occurred. For this reason, there is an essential requirement of "Green Cloud Computing" which is capable of producing explications that make cost effective and energy efficient IT resources. The concept of the Green Computing was started in 1987, with the awareness of sustainable development. In 1992, one consumer Energy Star plan is launched by the U.S. Environmental Protection Agency (EPA) [2].

Using the computers and further technologies in very effectual way, will increase the consumption of resources, energy efficient peripherals and decrease the electronic waste. This conception can be called as the Green Computing. Green computing will increase the resource efficiency and performance enhancements. Yashwant et al. discussed about the two aspects of Green computing as follows [20]:

- **Software**: Develop methods in a way to increase the efficiency of program, energy and storage.
- **Hardware**: Necessity of technologies to reduce the consumption of energy and economically efficient.

2. Applications of Green Computing

In order to increase the resource efficiency and performance there are seven application areas introduced for green IT which can be applied in Green cloud computing as follows;

- Proper management of power
- Energy efficient resources
- Design of data centers
- Virtualization of servers
- Environment sustainability design
- Eco-labeling for IT products
- Design of recycling methods

A. Proper management of power

Since green cloud computing encourages the technology to be environmentally-safe, energy efficient and cost effective solutions, it is very important to maintain proper power management in the cloud. If all requested services are catered to users by the cloud, there can be an opportunity of services that those might not be used for the full extent. This can result in additional amount of carbon is being produced to the environment and it can be very dangerous in terms of air pollution. So that, it is essential to check whether the resources are utilized or not.

In 2015, Rakshith and Sreenivas conducted a research on power efficiency of green cloud computing and they

have found that servers run at low utilization in data centers can be the key reason of energy inefficiency in data centers. Since there is a circumstance where even though usage of resources is fewer, the power consumed is more than the power spent on usage. As per their research, energy consumption can be identified as the main reason in content distribution system and these demand an accretion of networked computing resources from one or numerous service providers on datacenters across the world. In cloud computing systems and modern data center, this above mentioned expenditure is acting as a disapproving design parameter. The high carbon emission and energy cost are depending on the power and energy consumed by the computer equipment and the connected cooling system [3].

To address these problems, Rakshith and Sreenivas has proposed a new concept for increasing power performance of data centers, cloud application. These authors mainly characterize power performance of data center and cloud computing and proposed possible techniques to minimize the power requirement. There are number of technical algorithms which can be used to manage the power consumption, but Agglomerative Hierarchical Clustering algorithm is the mostly used algorithm and it is a 'bottom up' approach where each observation starts in its own cluster, and pairs of clusters are merged as it moves up the hierarchy. When the job is submitted by the user, it will be located in job queue and later it will be assigned to Virtual Machines. Prior to that, each Virtual Machine(VM) acts as a separate cluster and separate mechanics are used to calculate the energy efficiency of each VM and machines, with same energy is combined together to form a single group. VM's are categorized into three main cluster groups called as small size, medium size and large size cluster. When the power load is low, energy values will be less and if load growths then it will be moved to Medium size cluster. This algorithm helps to reduce the CO_2 emission into the environment and also it avoids the problem related to carbon emission into the environment. Resources will be in idle state if those are not mandatory or used at the specific time. Because of that power utilization in the ideal method, the CO_2 production into the environment is decreasing [3].

B. Energy efficient resources

With the increased usage of cloud computing, the use of huge data centers and high performing computers are expanding continuously. As a result, energy consumption by the data centers, energy dissipation in the environment, the amount of CO_2 emissions and the heat generated by processor chips are also rising gradually. For an example one data center occupies 50,000 square feet and requires 5-megawatt (mw) electricity which covers the power of 5000 households for one year. To avoid this problem, Green Cloud Computing has introduced. The aim of this is to develop high end computing systems like data centers and clouds to meet not only user's quality of service requirements, but also minimize the utilization of electric power. Apart from that it has defined to manage energy effectively and efficiently [4]. Most of the time cloud data centers remain underutilized. There are huge numbers of virtual machines running on top of these underutilized machines. Therefore, it needs high energy and power. In order to preserve significant volume of energy they are migrating virtual machines to other machines and hibernating such underutilized machines. As the data centers raise highly obsessed with energy efficiency, green cloud computing provides a rare opportunity to reduce data center power bills [5].

In cloud computing there are some metrics which are used to measure the energy efficiency of a data center [4]. Some of them are Power Usage Effectiveness (PUE), Thermal Design Power (TDP), Data Center infrastructure Efficiency (DCiE), Performance per Watt, Compute Power Efficiency (CPE), Green Energy Coefficient (GEC), Energy Reuse Factor (ERF), Carbon Usage Effectiveness (CUE), Data Center Productivity (DCP) and Space, Wattage and Performance (SWaP), Water Usage Effectiveness (WUE) [4]. According to Sasikumar et-al. [5], the most common metric is Power Usage Effectiveness (PUE). To calculate the Power Usage Effectiveness, total power entering to the data center should be divided by the power used by IT equipment.

$$\text{PUE} = \frac{\text{Total Facility Power}}{\text{IT Equipment Power}}$$

This equation can be represented as follows [5].

The power used by the support equipment is defined as overhead load and it mainly consist of power delivery, cooling systems and other infrastructure facilities like lightning.

Green cloud computing describes different techniques to minimize the power consumption. Some of them are reducing CPU power dissipation, use of renewable energy resources, use of energy efficient storages, reducing cooling requirements, use of advanced clock gating [4] etc.

C. Design of data centers

Data centers are the heart of cloud computing and running thousands of server side workloads, data storage and large scale of data and scientific processing. Today, large data centers consume hundred Megawatts of electricity. Therefore, improving data center efficiency is a major concern in the industry world. Past researches has described about system design and analysis of power, water, and carbon usage of the Massachusetts Green High Performance Computing Center (MGHPCC), a 90,000 square feet, 15 MW. MGHPCC is a data center that uses recent advances in cooling and power distribution to improve energy efficiency.

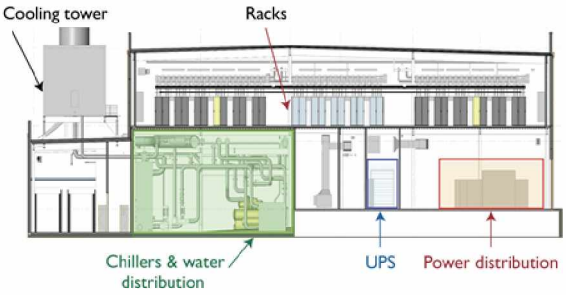


Figure 1. Layout of the MGHPCC data center.

MGHPCC consumes a favorable geographical location and green design to accomplish energy efficient operation. MGHPCC is situated in Holyoke in western Massachusetts. Due to its location, MGHPCC obtains inexpensive and abundant electricity, inexpensive real estate, and proximity to fiber-optic network backbones. Western Massacusetts has a cool climate and it enables the facility to employ free cooling as shown in the Figure 2. When data centers are located in cold areas, it reduces the cooling energy consumption [1]. The power infrastructure for the data center simulates a slight scale distribution network in the electric grid. The infrastructure contains substations, feeders, transformers, and switchboards that feed power to the computing and cooling infrastructure. When developing a green data center cooling infrastructure, data center monitoring, power infrastructure and physical layout are the major areas that should be considered.

D. Virtualization of servers

Creating virtual resources such as desktop, operating system, file, server, storage or network are called as the virtualization. There are seven main types of virtualization as; Server virtualization, Application virtualization, Desktop virtualization, Hardware virtualization and Network virtualization. For green cloud computing server virtualization plays major role by masking of server resources, including the number and identity of individual physical servers, processors, and operating systems, from server users. In order to separate one single physical server into several remote virtual environments, administrator can use a software application. The main three approaches for the server virtualization are paravirtual machine model, virtual machine model and virtualization at the operating system layer. In 2012 Sasikumar and Yuvapriya has discussed about operating the servers in a Cloud data center. In order to minimize power consumption within the data center VM scheduling algorithm can be used. Power-aware and thermal aware scheduling are the main two types of green scheduling systems for supercomputers. In order to minimize the overall data center temperature, jobs can be scheduled and that pattern is called as the thermal-aware scheduling. It helps to decrease the energy needed to control the data center cooling systems. Power-aware scheduling arranged to decrease the server's total power by scheduling the jobs to nodes. Operating the servers is the most valuable function within a Cloud data center. VM schedules algorithm that minimizes power consumption within the data center [13].

E. Environment sustainability design

The major concern of Environment sustainability design (ESD) is on reducing or completely eradicating undesirable environmental impacts in the long term with the aid of attentive design. In a study conducted by Microsoft, Accenture and WSP in 2010, it has been identified that the reduced environmental footprint of cloud computing is mainly influenced by several key factors such as Dynamic Provisioning, Multi-Tenancy, Server Utilization and Data Center Efficiency [21]. Dynamic provisioning refers to reducing the over-allocation of infrastructure for which the datacenters maintain servers considering current demand thus resulting in lesser consumption of energy. The application instances are shared between client organizations using the multi-tenancy approach which assists in leveling the peak demand as well as reducing the general energy consumption and related carbon emissions. Server utilization indicates operating servers at higher utilization rates with the aid of virtualization techniques thereby decreasing the number of active servers. Though high server utilizations imply more power consumption, highly utilized servers are capable of accommodating workload with same power usage. Moreover, data center efficiency, expressed by power usage effectiveness (PUE), fundamentally affects the energy usage in cloud computing. A higher PUE is achieved through data center infrastructure designs including modular container design, air or water evaporation based cooling, or advanced power management through power supply optimization.

F. Eco - Labeling

Eco-labeling refers to the mechanism of accreditation given to a product or a service by an unbiased third party which are considered to have less effects on the environment and therefore environmentally desirable. Eco-labeling comes under Type 1 of the three key voluntary environmental labeling types recognized by the International Organization for Standardization (ISO).

3. Vendor Involvement

With the necessity for going green getting stronger than ever, many leading companies have started taking interest in environmental friendliness. Thus, in regards to green cloud computing, the foremost cloud providers such as Amazon Web Services (AWS), Microsoft, Google and IBM has taken some major steps concerning adoption of a greener cloud at the infrastructure level.

A. AWS

Microsoft Amazon Web Services (AWS), the cloud platform provided by Amazon, is one of the leading cloud vendors offering services such as Infrastructure as a service (IaaS), Platform as a service (PaaS) and packaged Software as a service (SaaS). In regards to building a green cloud platform, AWS has taken certain prominent actions in the recent years, promising leadership in supporting clean energy while also being committed to solely rely on renewable power along with building solar and wind farms.

In a report released by environmental activist group Greenpeace in 2017, it has been discussed on how green the Amazon's cloud is along with relevant statistical data [22]. Prioritizing the environment, AWS has joined major tech companies in filing an amicus brief encouraging the Clean Power Plan of the US Environmental Protection Agency which focuses on restraining power plant emissions. Moreover, AWS is also a part of the non-profit organizations concentrating on the environment such as American Council on Renewable Energy. AWS has stated that in 2016, 45% of its energy was from renewable sources and it is expected to raise up to 50% by the end of 2017.

Nevertheless, Greenpeace states that the AWS US East region facilities located in Virginia are only about 3% clean with about a third of the power supply being associated with coal, nuclear and natural gas [22]. However, the AWS regions such as US West (Oregon) and EU (Frankfurt) are much greener with 85% of power being generated by renewables for data centers in Oregon. As per the statistics of Greenpeace, energy demands of AWS are met having 30% of coal, 26% of nuclear generation and 24% of natural gas while only 17% percent of the energy requirements are covered with clean energy. Greenpeace also specifies that Amazon is the least transparent company in regards to disclosing its energy footprint.

Nonetheless, in January 2018, AWS has been able to achieve 50% renewable energy usage [23]. Furthermore, the company has initiated 10 renewable energy projects. The projects include solar farms in Virginia such as Eastern Shore, 80 megawatt solar farm in Accomack County, and five 20 megawatt solar farms Buckingham, New Kent, Sappony, Scott and Southampton in Buckingham, New Kent, Sussex, Powhatan and Southampton counties respectively. Additionally, the projects also consist of wind farms, for example, Amazon wind farm Indiana - Flower Ridge, which is a 150 megawatt wind farm in Benton region, Amazon wind farm North Carolina - Desert Wind which is a 208 megawatt wind farm in Perquimans and Pasquotank regions and lastly Amazon wind farm Ohio – Timber Road, which is a 100 megawatt wind farm in Paulding region. The aforementioned projects are anticipated to produce over 2 million megawatts of energy per year which should be sufficient to power a city size of Atlanta, Georgia. With these advancements, AWS states that the company is always striving toward cleaner and renewable energy sources [23].

B. Microsoft

Microsoft is one of largest ICT Company that has committed efforts to becoming green. Their data centers and its operations have reduced carbon radiations by 9.5 metric tons. Apart from that 44 percent of Microsoft data centers come from renewable resources like new wind, solar energy and hydro. In other words, Microsoft purchased 500 Megawatts from these resources to maintain their data centers. Also, they have a mechanism to recycle consumer e-waste and nearly 10 million of them have recycled by today [6]. Recently Microsoft launched a project called 'Project Natick' to test underwater data centers by using submarine technology. Ultimate goal of this project is to take the advantage of renewable marine energy and also to cool the equipment. Microsoft eventually hopes to develop under water data centers with two decades' life spam, deploy over five-year periods where computer hardware is replaced at the end of each deployment.

C. Google

According to the statics of Greenpeace report on the greenest IT companies of 2017, Google is the leading one [22]. Major reason for this is the sustainable data centers that are maintained by the Google Cloud. To maintain the sustainability, they are using the concepts like renewable energy, efficient data centers and circular waste management [8]. Google has maintained carbon neutral operations in last few decades and according to them, it will continue in the future as well. Google is maintaining 14 data centers all over the world. Those data centers are well designed to maximize the efficiency and minimize the environment impact. To increase the efficiency, they are using technologies like smart temperature, smart lighting controls, advanced cooling techniques and a redesign of the distribution of power to reduce energy loss. Altogether on average Google data centers use 50% less energy than others. Also, the G Suite products (Gmail, Calendar, Docs, and Drive) which are managed by Google, have reported reductions in IT energy use and carbon emissions of 65% to 85%. According to Google when the user chooses Google Cloud Platform to run computers, store data and develop applications, the digital footprint is offset with clean energy, which reduces the impact on the environment [9].

D. IBM

IBM is another cloud vendor which has focused on "Green" for over 35 years. It has used green technology to build the company's largest data center. To do that, they have used a variety of green technologies like high-

density computing systems that use server and storage virtualization, energy efficient power and cooling systems [12]. Also, they have followed a green infrastructure which includes data center assessment and services, consolidation and Optimization Services, Tivoli energy management solutions, Tivoli Maximo asset management solutions, asset management services, Tivoli storage management and information management solutions. Apart from those, IBM has introduced sustainable solutions like strategic carbon management, carbon intelligence and sustainable logistics design and asset management [10].

4. Discussion

The focus of the paper is to discuss the green IT attributes which are adopted in cloud computing domain in order to achieve green cloud computing and the efforts of the cloud vendors in becoming green. It has been discussed how several green IT aspects can be applied in cloud computing in order to achieve green cloud computing.

As far as cloud vendors are concerned, all prominent cloud providers like AWS, Microsoft, Google and IBM have made significant efforts in becoming environmental friendly. While vendors like AWS, Microsoft, Google have all committed to entirely rely on renewable power, they have also started building data centers powered by renewable sources. The Table 1 and 2 demonstrates the scores assigned by the environmental activist group Greenpeace in 2017 on clean energy usage for the major cloud vendors [22].

Table 1: Greenpeace Report Statistics Related to Major Vendors.

	Final Grade	Energy Transparency	Renewable Energy Commitment	Energy Efficiency	Renewable Procurement	Advocacy
AWS	C	F	D	C	C	B
Google	A	B	A	A	A	A
IBM	C	C	B	C	C	F
Microsoft	B	B	B	C	B	B

Table 2: Grades Given by the Greenpeace in 2017.

	Clean Energy Index	Natural Gas	Coal	Nuclear
AWS	17%	24%	30%	26%
Google	56%	14%	15%	10%
IBM	29%	29%	27%	15%
Microsoft	32%	23%	31%	10%

Greenpeace has evaluated the performances of each vendor based on sources such as directly offered information, public information by the vendors and reporting bodies while also taking media coverage and published reports into account. The final grades for each vendor have been assigned as per 20% weight each for Transparency, Renewable Energy Commitment & Siting Policy and Advocacy, 10% weight for Energy Efficiency & GHG Mitigation and assigning Renewable Energy Procurement, including current energy mix with a weight of 30% [22].

5. Conclusion

Cloud computing is a topic which has been able to transform the organizational perspective of IT resources with it bringing out various benefits. The advantages of cloud include it being much more energy efficient than having individual data centers. However, cloud computing can still lead to certain negative environmental impacts. Hence, the paper has discussed about the adoption of green IT attributes to the cloud along with how green the cloud is based on certain criteria, taking major cloud service providers such AWS, Google, Microsoft and IBM into account. Consequently, while the major cloud providers have several undesirable effects on the environment to a certain extent, they are advancing towards becoming green aiming green cloud computing.

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