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Green Cloud Computing - A Greener Approach To IT

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***Abstract*:** *With the increasing growth of large data storage and computational demands, Green Cloud Computing is known to be a broad area for research. In today's green IT, the energy consumption of software has largely increased, so it needs to be economic and sustainable. While cloud computing itself is a much greener alternative to individual data centers with lesser number of servers being used, it cannot be neglected the fact that the data centers utilized by cloud vendors are still a major source of carbon emissions to the environment. In this review firstly, a brief discussion of Green Computing and its architecture is given, then various other areas of interest are discussed and reviewed further.*
Keywords: *Green Cloud Computing, Carbon emissions, Infrastructure*

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I. Introduction

Cloud computing is a dynamic field of information and communication technologies (ICTs), that introduces new challenges for environmental protection. It has produced an impressive way of virtualizing servers and data-centers to make them more energy efficient. Cloud computing technologies have a variety of application domains, since they offer scalability, are reliable and trustworthy, and offer high performance at relatively low cost. Here, computing is delivered as a utility on a pay-as-you-go basis.

Traditionally, business organizations used to invest huge amounts of capital and time in acquisition and maintenance of computational resources. The emergence of Cloud computing is rapidly changing the ownership-based approach to a subscription-oriented approach by providing access to scalable infrastructure and services on-demand.

Users can store, access, and share any amount of information in the Cloud. That is, small or medium enterprises/organizations do not have to worry about purchasing, configuring, administering, and maintaining their own computing infrastructure. They can focus on sharpening their core competencies by exploiting a number of Cloud computing benefits such as on-demand computing resources as well as faster and cheaper software development capabilities at low cost.

The cloud computing revolution has helped businesses transform their existing server infrastructures into dynamic environments by expanding and reducing the server capacity as needed. These technologies have the potential to improve energy efficiency and to reduce carbon footprints and e-waste. These features can transform cloud computing into green cloud computing.

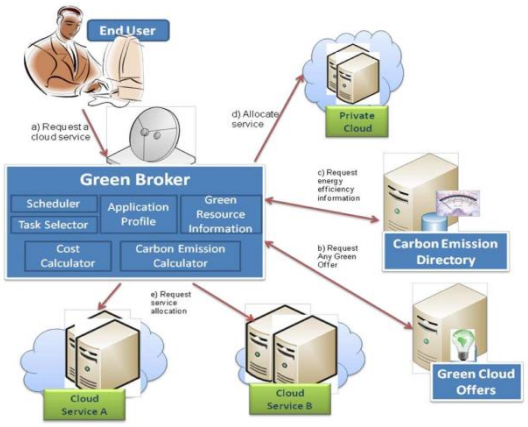
Now, 'Green cloud computing' is a coined term that means making the practices and approaches of using technological advances like computing and other IT resources sustainable for potential environmental benefits. In a broader sense, it's the practices and procedures of designing, manufacturing, using of computing resources in an environment friendly way while maintaining overall computing performance and finally disposing of them in a way that reduces their environmental impact.

The growing number of companies around the world makes a significant impact on the environment which implies a great need to use data centers, an increase in the daily commute of workers, and an influx of office materials and supplies needed on a daily basis. Green cloud computing provides solutions to these looming environmental issues by providing options that can lower emitted carbon footprints around the world.

II. Green Cloud Architecture

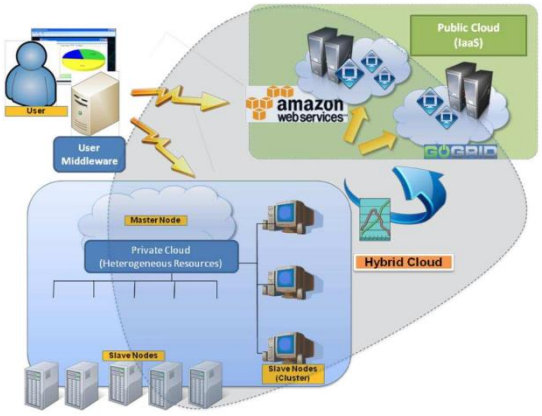
In the Green Cloud architecture, users submit their Cloud service requests through a new middleware called a Green Broker that manages the selection of the greenest Cloud provider to serve the user's request. A user service request can be of three types i.e., software, platform or infrastructure. The Green Cloud framework is designed in such a way that it keeps track of the overall energy usage of serving a user request. It relies on two main components, Carbon Emission Directory and Green Cloud offers, which keep track of energy efficiency of each Cloud provider and also give incentive to Cloud providers to make their service "Green". The Green Broker then calculates the carbon emission of all the Cloud providers who are offering the requested

Cloud service. Then, it selects the set of services that will result in least carbon emission and buys these services on behalf of users. From the user side, the Green Broker plays a crucial role in monitoring and selecting the Cloud services based on the user QoS (Quality of service) requirements, thereby ensuring minimum carbon emissions for serving a user.



As shown in the above figure, cloud providers can register their services in the form of "green offers" to a public directory which is accessed by the Green Broker. The green offers consist of green services, pricing and the time when it should be accessed for the least carbon emissions. The Green Broker gets the current status of energy parameters for using various Cloud services from the Carbon Emission Directory which maintains all the data related to the energy efficiency of a particular Cloud service. This data may include PUE(Power Usage Effectiveness) as well as the cooling efficiency of the Cloud datacenter which is providing the service, the network cost and carbon emission rate of electricity.

There are three key models in cloud computing : IaaS (Infrastructure as a Service), PaaS (Platform as a Service), and SaaS (Software as a Service). IaaS and PaaS provide services to individualist software vendors and introducer, while SaaS gives services to finished users. A typology of cloud computing must consider the degree of availability it offers in order that it is often ranked as private, public, hybrid,and/or community and it can be seen in the figure below.



Since a user can use Cloud to access any of these three types of services (SaaS, PaaS, and IaaS), therefore the procedures of serving them should also be energy efficient.

a) SaaS Level: Since SaaS providers mainly offer software installed on their own data centers or resources from IaaS providers, the SaaS providers need to model and measure energy efficiency of their software design, implementation, and deployment. And so, for serving users, the SaaS provider chooses the data centers which are not only energy efficient but also near to users.

b) PaaS Level: PaaS providers offer in general the platform services for application development. The platform facilitates the development of applications which ensures system wide energy efficiency. This can be done by inclusion of various energy profiling tools like JouleSort which is a software energy efficiency benchmark that measures the energy required to perform an external sort.

c) IaaS Level: Providers in this layer play the most crucial role in the success of the entire Green Cloud Architecture since the IaaS level not only offers independent infrastructure services but also supports other services offered by Clouds. They use the latest technologies for IT and cooling systems to have the most energy

efficient infrastructure. By using virtualization and consolidation, the energy consumption is further reduced by switching-off unutilized servers. What's more is that the Cloud provider also designs various green offers and pricing schemes for providing incentive to users to use their services during off-peak or maximum energy-efficiency hours.

III. Different Approaches to Migrating to Green Cloud Computing

Green cloud computing relies on processes that make datacenters more energy efficient. Companies can migrate to green cloud computing through virtualization or efficient power practices.

- **Virtualization**

Many organizations deploy servers that run only at a fraction of their capacities, often because they want to dedicate such systems to a specific application. This is highly inefficient because it results in an excess capacity that doesn't get consumed, leading to higher energy consumption and operating costs. Virtualization creates an abstraction layer over the physical server, allowing IT administrators to generate multiple virtual machines (VMs). This enables the organization to run multiple VMs, operating systems (OSs), and applications on the same host—essentially partitioning the physical server into numerous virtual servers. This as a result reduces the number of physical servers that an organization needs. Consolidating physical servers can minimize power consumption and cooling, potentially cutting energy bills by a huge amount.

- **Efficient power supply and power management practices**

From the energy-efficiency perspective, organizations can achieve energy efficiencies in two ways: using clean energy and improving power efficiencies in data centers. By using renewable energy, companies can reduce GHG (greenhouse gasses) emissions associated with compute-intensive workloads such as deep learning and grid-computing workloads. Organizations can also achieve energy efficiencies by leveraging green algorithms in their data centers that can minimize the resource consumption for a given task significantly, potentially reducing energy usage and carbon footprint. Algorithms could also route traffic to datacenters that use renewable energy or where electricity is less expensive. When used, these algorithms not only reduce the amount of energy consumed but also minimize operating costs. The steps below can help you transition easily to green cloud computing:

1) Select a carbon-aware provider.

Choose cloud vendors and cloud services that use renewable energy rather than those that run on fossil fuels. The Green Web Foundation (GWF) offers a host directory that lists all the renewable-energy-powered providers.

2) Optimize your cloud environment.

Many of the cloud optimizations that minimize costs also reduce server utilization and GHG emissions. To minimize energy consumption, you'll need to optimize the current setup and have complete visibility over your usage.

3) Ensure you have solid carbon measurement and reporting plans.

You should connect your corporate responsibility teams with cloud vendors or cost optimization groups to understand the organization's carbon footprint. Because most cloud vendors don't share this information, having a solid cloud measurement and reporting plan can help you with sustainability reporting.

4) Keep innovating.

When you shift to the green cloud, the decisions that you make can directly determine how sustainable the company is. Unprecedented levels of innovation can help you unlock the true potential of green cloud computing, leading to a greener planet.

5) Dynamic Provisioning

In a traditional setting, data centers and private infrastructure used to be maintained to fulfill worst case demand. Thus, IT companies end up deploying far more infrastructure than needed. Such scenarios can be readily managed by Cloud infrastructure as the virtual machines in a Cloud infrastructure can be live migrated to another host in case a user application requires more resources.

IV. Attaining Greener Data Centers

Cloud service providers typically employ multiple strategies to attain greener data centers. These efforts target efficiency improvements in one or more of the following areas:

- **Energy Sources**

The provider uses renewable energy as much as possible to power its data centers which often includes wind or solar energy, along with large battery banks for storing the collected energy. Some providers use renewable energy credits (RECs) to offset their carbon footprint, giving them license to claim that their data centers use 100% renewable energy. However, RECs are not the same as eliminating the use of fossil fuels.

- **Facilities**

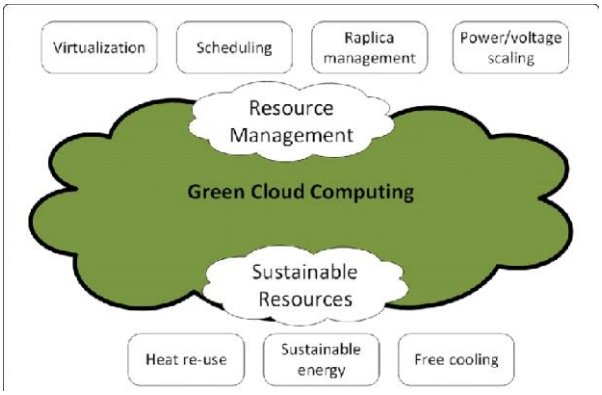
The provider takes measures to use energy more efficiently in its data centers. For example, a provider might locate a data center in a cold climate, underground or even on the ocean floor. The provider might also find ways to utilize the excess heat generated in the data centers, such as warming nearby buildings. Additionally, providers might use machine learning or other advanced technologies to monitor and optimize energy use. Modifying the data center floor layout to improve air circulation or implementing water cooling systems to handle equipment-generated heat are other strategies.

- **Infrastructure**

The provider optimizes the hardware and software infrastructure. For example, a provider might deploy hardware that consumes less energy or use strategies such as dynamic voltage and frequency scaling (DVFS) to reduce power consumption. The provider might also maximize resource utilization, such as implementing virtualization that involves using specialized software to create a virtual or software-created version of a computing resource rather than the actual version of the same resource, or through software-defined infrastructure, to reduce the number of servers and storage devices.

- **Workflow**

The provider uses multiple strategies to optimize workflows at every level which might include shifting workloads to different times, modifying applications to reduce network traffic, optimizing storage and server caches, automating routine tasks or taking any number of other steps to reduce energy usage.



V. Discover How Green Cloud Computing Can Reduce Our Carbon Footprint

Traditionally, organizations have leveraged cloud computing to unlock cost-effectiveness, agility, and security benefits. However, sustainability is becoming increasingly essential, hence the increasing popularity of green cloud computing. Given how pervasive the internet has become, today's data centers consume an estimated 200 terawatt hour (TWh) each year. This is more than the total national electricity consumption in some countries.

Many companies right now are leaning on the cloud services as many technological applications and practices that can reduce environmental impacts are being developed daily. Green cloud computing makes it possible to maintain and enhance business operations and processes while looking after the environment.

The information and communications technology (ICT) sector accounts for between 2% and 6% of the global greenhouse gas (GHG) emissions. This puts the ICT's GHG emissions on par with that of the aviation industry. For now, these figures have remained largely the same due to significant efficiency gains arising from the use of hyperscale data centers by major public cloud vendors. However, companies must do more to reduce carbon footprint by 45%, as set by the Paris Agreement.

Cloud datacenters	Location	Estimated power usage Effectiveness	% of Dirty Energy Generation	% of Renewable Electricity
Google	Lenoir	1.21	50.5% Coal, 38.7% Nuclear	3.8%
Apple	Apple, NC		50.5% Coal, 38.7% Nuclear	3.8%
Microsoft	Chicago, IL	1.22	72.8% Coal, 22.3% Nuclear	1.1%
Yahoo	La Vista, NE	1.16	73.1% Coal, 14.6% Nuclear	7%

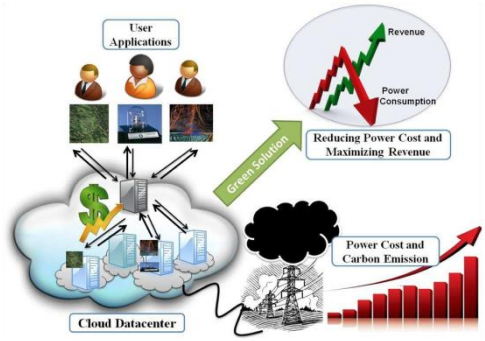
In a study conducted by Greenpeace [11] comparing significant cloud datacenters, it can be seen that none of the cloud datacenters in the table above can be called as green. One reason why that is, is that more often than not, cloud providers are more interested in electricity cost reduction rather than carbon emission reduction. And since the collective demand for computing resources is expected to only further increase

dramatically in the coming years, the Cloud phenomenon may aggravate the problem of carbon emissions and global warming as even the most efficiently built datacenter with the highest utilization rates will only mitigate, rather than eliminate, harmful CO2 emissions. This is why a greener way of Cloud Computing is the need of the hour as it focuses on designing efficient clouds with green characteristics like power management, virtualization of servers, eco-labeling, load balancing, reusability, recyclability etc.
Below are the ways in which Green Cloud Computing has been both a boon and a bane.

Advantages
1) Reduces paper waste: Paper has been a staple in offices round the world for many years, but the cloud has dramatically reduced the necessity to make physical documents and files also can be stored and shared within the cloud, improving energy efficiency also as security, as duplicates are often created easily during a backup server.
2) Reduces energy consumption: Cloud service wage-earners crowd thousands of servers within their amenities, allowing them to exploit well-organized processes available to the mowing to their bulk. The cloud offers a spread of eco-friendly benefits to businesses .
3)Take advantage of government incentives: If you're noticing a trend of cash saving benefits, it's because it really pays to travel green. The Cloud helps to save lots of enterprise funds on its own, but the residual effects of cloud adoption also cause price savings. Incentives for corporate energy efficiency, starting from tax incentives to rebates are offered by both the local government and federal agencies.

Disadvantages
• Implementation Cost is High**:** The starting investment for green computing is taken into account to be high by medium-sized and little organizations. Green computing remains not yet affordable to everyone.
• Evolving Technology: It will be tough to adapt to this. Green cloud computing is still a new and developing technology, so it might not be easy for everyone to familiarize themselves with it instantly. Applications that widely make use of green cloud computing are employed within the following areas in companies and organizations:
a) Management of energy in Data Centers
b) Green Wireless Networks
c) Green Computing with an Algorithm.
d) Green Parallel Computing with Big Data Networks

VI. Impacts of Green Cloud Computing On The Environment



Fewer Carbon Footprints Because Of Remote Workers

Cloud computing allows businesses to store their data on the internet, which means it can be accessed by anyone given the authority, no matter the location or whatever device is being used. This opportunity presented gives businesses and companies the flexibility to gear their employees toward remote working.

Working remotely gives your workers the benefit of escaping the daily commute, which requires them to fuel their cars regularly. With the chance to allow your personnel to work at home or any place that would better suit their efficiency and productivity, you also help the environment by cutting down on fuel emissions.

Even though you have many employees still working for you, you do not have to acquire a big space with your office. You can get a small office space which reduces your consumption of water and electricity.

Saving The Environment By Being Paperless

Gone are the days where you had to print and store all files received in your email or all of the reports you have prepared for your immediate head. With the innovative features of storing data in the cloud, you do not need large filing cabinets to store your printed copies. Green cloud computing makes it possible for companies

and organizations to go paperless.

As long as you are connected on the internet, you can leverage cloud storage options like Google Drive, OneDrive, Dropbox, or SharePoint. These storage options allow you and your whole team to go paperless without sacrificing the entire organization's functionality. With the ease of use, as these cloud storage options offer drag and drop features for all your files, you can still expect productivity within the whole team or organization even when working remotely.

With the emergence of Adobe Sign or DocuSign, there is no need to print any file for a single signature. These cloud-based technology innovations will allow you to download any document, fix your signature and send it back to whoever needs it without printing any pages and with just the use of your computer.

The use of these green cloud computing tools makes it possible for organizations in different industries to reduce paper product consumption, if not eliminating it. This approach creates a significant impact on the environment as you cut down the need to regularly purchase paper products, shred your documents, or dispose of your files.

Reduction Of Your Power Consumption To Decrease Energy Use

Reduction of your company's power consumption does not only mean turning off your computer or your workstation lights when not in use. Though this can make a huge difference, you have to understand the gravity of consumed power when your company runs on-location servers.

After you have logged out, shut down your desktop and make your way home, these on-premise servers need to have a constant power supply to make your servers work. You also need to have a running cooling system 24/7 to avoid your servers from overheating, and disposing of these machines after its shelf life will be even another thing you need to tackle.

Switching to the cloud can reduce your reliance on these on-premise servers. It means that you also need fewer machines in your office location, thus less space, and cooling requirements, leading to a reduced power consumption rate. Savings from these freed up capital expenditures can be allocated to other environment-friendly projects or business development ventures like enhancing your marketing strategy campaigns.

Dematerialization That Decreases Greenhouse Gasses Emissions

When you opt to have an on-site data center, the materials used to build it goes a long way and produces greenhouse gasses (GHG) on its life cycles. These GHGs are emitted as raw materials for your equipment. The same gasses are emitted as the equipment is being assembled and transported to its location. As you use the equipment, more gasses are produced as well as you come in terms of terms.

As you move to the cloud, you decrease the emission of these gasses, and you practice dematerialization. Dematerialization means the replacement of physical products with virtual alternatives. As you begin to rely on cloud services, you shy away from using GHG emitting physical products, which has a significant impact on the well-being of the environment.

Reducing your leverage on physical products like paper, pieces of machinery, equipment, and hardware also decreases the amount of waste garnered when these products call the need for disposal. Green cloud computing even allows you to focus your time and effort on other profitable projects than dealing with mundane tasks like IT work and downtime issues.

VII. Conclusion

Cloud computing may be a new paradigm that integrates already-existing technologies so as to extend the efficiency of resource use. The results of using these technologies are varied. The provider of such services and the authors of studies accepted by enterprises interested in environmental safeguard have highlighted both favorable and unfavorable aspects of the effects of cloud computing on the ecosystem.

The benefits provided by cloud computing technology have now gone a long way. Aside from offering customers convenience, flexibility, scalability, and cost efficiencies, it has become a way to innovate processes and operations that would not add to the looming and growing environmental issues worldwide. Many have regarded technological advances to be a driving force for environmental destruction. However, technologies like cloud computing can be a start to make up and help address environmental concerns. Relying on green cloud computing can make your company reach a positive bottom line, enhance workforce productivity or innovate business processes, and make the environment a better place.

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