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Adopting Cloud-Based Techniques to Reduce Energy Consumption: Toward a Greener Cloud

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***Abstract*—**The cloud computing industry has set new goals for better service delivery and deployment, so anyone can access services such as computation, application, and storage anytime. Cloud computing promises new possibilities for approaching sustainable solutions to deploy and advance their services in this distributed environment. This work explores energy-efficient approaches and how cloud-based architecture can reduce energy consumption levels amongst enterprises leveraging cloud computing services. Adopting cloud-based networking, database, and server machines provide a comprehensive means of achieving the potential gains in energy efficiency that cloud computing offers. In energy-efficient cloud computing, virtualization is one aspect that can integrate several technologies to achieve consolidation and better resource utilization. Moreover, the Green Cloud Architecture for cloud data centers is discussed in terms of cost, performance, and energy consumption, and appropriate solutions for various application areas are provided.

***Keywords*—**Greener Cloud, cloud computing, energy efficiency, energy consumption, metadata tags, Green Cloud Advisor.

I. Introduction

GLOBAL warming is an increasingly pressing environmental problem due to rising energy consumption and carbon dioxide emissions. Computer-related electronic machines such as data centers, networking devices, and computing devices consume a large amount of energy generated by thermal power plants. Essentially fossil fuel resources like oil and coal are used to generate energy in these power plants, exacerbating various environmental problems, such as detrimental climate change and ozone layer depletion [1]. Therefore, industries are increasingly adopting optimized energy consumption and greenfield solutions to reduce global warming effects. Cloud-based architectures also consume a great deal of energy needed to run their machines and systems to ensure 24/7 availability [2]. Today, existing data centers and all racks of servers consume approximately 2% of the world's electricity [3].

In terms of the environment and economy, the sustainability of these technologies has tremendous implications for societal welfare. Thus, the electricity demand by the virtual world's infrastructure should be addressed [3]. Lately, businesses and organizations have been adopting sustainable solutions for their operations and services to reduce the environmental effects and carbon footprints by lowering operational costs. Cloud computing provides a sustainable architecture to reduce energy consumption levels. It is an emerging technology that enables remote accessing computing resources like applications, storage, video games, services, and multimedia services with the help of broadband connectivity.

Using an energy-efficient solution helps reduce carbon emissions and deals with executing the same tasks as traditional computing methods while consuming less energy with lower costs. The cloud-based IT industry has significant energy consumption and affects the environment. Cloud services providers are not in agreement on sacrificing performance or expending more cost for extending service delivery; therefore, a balanced approach is required to deliver the same services but using less energy [4].

Cloud-based computing is growing enormously, commensurate with the increased demand for computing resources. It enables users to purchase specific computing and database resources and pay only for their use. This usage model allows users to scale resources on demand according to their needs. Increased power usage in cloud-computing may result in costlier hardware resources of cloud infrastructure, which can also lead to more carbon dioxide emissions. Therefore, so-called *green computing* plays a significant role in optimizing and decreasing the energy consumption of computing machines, servers, networks, databases, and cooling systems [5]. Additionally, it reduces the cost of operating in-house IT infrastructure by reducing the usage of hazardous materials. It also helps to dispose of electronic waste properly with a minimal impact on the environment.

II. Background Information on Virtualization, Green Cloud Computing, and Increased Energy Consumption

Cloud computing technologies must be adequately developed, and further R&D efforts are required. Currently, the approach depends on utilizing a significantly large number of data centers. A single data center encompasses hundreds or even thousands of physical machines and other computing resources arranged in hundreds of racks to allow them to run millions of virtual machines (VMs). An excellent example is Google, which is among the prominent cloud-based companies. Google can deliver its services to consumers and end users by relying on some of the capabilities offered by the cloud. However, massive data centers are required for all these services to be successfully delivered to customers in real-time. Currently, Google is running at least 14 data centers with approximately two million servers.

Virtualization continues to become an exciting conversation, particularly in light of its initiation by institutions such as IBM,

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which started by creating partitions of their mainframe computers to increase their processor utilization, a key point for VMs. The advantages of VMs include increased portability, low maintenance costs, manageability, and security [3]. Another significant advantage that stands out with VMs is how they present their lack of dependency, as the VM will not in any way impact the workability of the physical machine [5]. Furthermore, it prevents the guest operating system from gaining direct access to the hardware. Overall, VMs present multiple advantages, including how they significantly increase hardware utilization while reducing the number of physical servers required to run a fully operational data center.

Unfortunately, among the chief dilemmas of cloud computing and the reliance on physical data centers is the energy required to ensure that they are fully operational. Enormous energy is required to achieve critical roles such as storage, communication, and data processing [5]. Furthermore, these high energy requirements negatively affect the environment due to increased carbon emissions. With the advent of cloud computing and the heavy adoption of technology, reducing carbon emission is imperative. Furthermore, the high consumption of energy translates to higher operational costs. Therefore, extensive studies must be conducted to establish techniques for reducing energy consumption and embracing a greener cloud.

Need for Energy-Efficient Techniques for Cloud Infrastructure

Energy consumption in cloud-based data centers is estimated at 1.4% of the total power consumption, increasing annually by 12%. Green cloud computing is a new research area that has attracted researchers worldwide [6]. Presently, researchers are working on technologies that balance energy efficiency requirements with performance requirements. However, reducing cloud infrastructures' energy consumption may cause Service Level Agreement (SLA) violations. SLA violations cover all agreements between consumers and service providers. An excellent example is how providers may decrease the cost of running data centers but overcharge their consumers. Violations of SLA result in a penalty to cloud service providers that can significantly affect their bottom line.

Accenture published a report about the energy consumption of cloud infrastructures, claiming that small and mid-size IT organizations can decrease up to 90% of carbon dioxide emissions if they migrate their services to cloud infrastructures [7]. Furthermore, at least 60% of the emissions can be reduced if these organizations establish the entire infrastructure on the cloud. Most cloud service providers are interested only in cost reduction related to electricity rather than carbon emissions. It is vital for cloud service providers to factor in energy consumption to reduce global warming.

If all the cloud infrastructures are built on the green computing principle, the advantages of cloud computing can also extend to environmental protection. For example, cloud infrastructure connects high-speed network connections and VMs with temperature control devices. In Fig. 1, four conditions are highlighted in which a system uses energy inefficiently; these conditions represent inefficient usage, like a drop or loss of energy. An energy drop means energy is transmitted to the system but not used by the system, such as in the case of electricity drainage due to transfer or conversion. The second reason can be the cooling of hardware resources [3]. Another reason for energy loss can be over-the-limit usage, like cooling a system to a maximum at night when the temperature is already low.

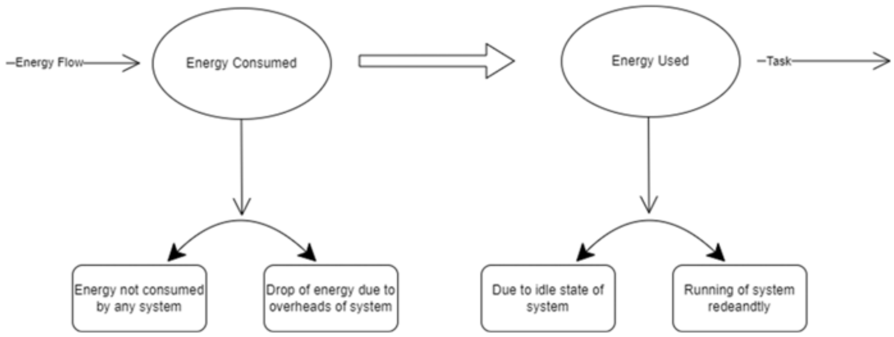

Fig. 1 Four Conditions in which a system can drop energy inefficiently

Roles of Reducing Energy Consumption in Cloud Infrastructures

Cloud infrastructure can provide a powerful and effective computing environment with the help of virtualization. Organizations have widely accepted this idea to reduce in-house hardware and software investment. It becomes more advantageous when thousands of cloud users share the same resources and pay per use-without any capital investment. Moreover, these infrastructures provide scalability and dynamic provisioning of resources. The latest trends in cloud services are microservice architecture and service-oriented architecture (SOA). These architectures are designed to meet the intensive computational needs of the users. Moreover, cloud services can access the internet globally with colossal computing infrastructures.

III. Green Cloud Computing and How it Contributes to a Sustainable Future

A. Energy Management

Renewable energy to power data centers across the globe is a critical aspect that defines green cloud computing [3]. Unfortunately, powering an entire data center with green energy has yet to be achieved. However, previous efforts have seen firms use up to 50% of renewable energy to power their data centers [5]. Furthermore, integrating battery banks allows energy storage and can be utilized when less energy is stored in the batteries. As a result, there is a significant decrease in the carbon footprint.

B. Cloud Facility

Even though relying on renewable energy should be seen as a possible way forward for cloud computing, energy efficiency should always be part of the picture. Cloud service providers have been at the forefront of exploring options such as locating their data centers on the ocean floor or in icy climatic conditions. These providers have proven ways of saving resources and energy by cooling down their servers. Another exciting technique cloud service providers use is utilizing excess heat generated within the data centers. Integrating innovative technologies to execute key roles, such as monitoring and optimizing energy consumption, is a critical alternative [3]. This aspect can be achieved by leveraging the available solutions and ensuring that valuable insights are consistently relied on to design and implement data centers.

C. Smart Infrastructure

Cloud service providers have been exploring options that help simplify ways of deploying software and hardware infrastructure and consuming less energy, thereby minimizing carbon emissions. For example, deploying hardware with the capabilities of minimizing power consumption and integrating Dynamic Voltage and Frequency Scaling (DVFS) ensures that energy is optimized, thus maximizing power saving.

D. Workflow Management

Optimizing workflows is an avenue that cloud providers across different levels could explore further. For example, some initiatives could include shifting workloads, optimizing storage, modifying applications, and reducing the energy required to run data centers. In addition, the available data can be leveraged to design optimized workflows that save time, resources, and energy.

IV. Overview of Energy Reduction Techniques

Different hardware and software-based techniques and practices can be implemented and ensured by quality assurance practitioners [7]. Furthermore, creating awareness and establishing standard policies are other practices to reduce the energy consumption of cloud infrastructures that are critical across industries and enterprises. Therefore, it is vital to educate and train all personnel in an organization on the importance of reducing energy consumption and even suggest ways and frameworks that would be used to reduce energy consumption.

Virtualization technology provides VM management and energy efficiency through better utilization of resources. It maximizes efficiency by sharing physical resources and improves service availability with the help of dynamic migration. Furthermore, multiple instances of the operating systems can be initiated through the hypervisor. As a result, virtualization can attain higher hardware utilization rates and reduces cost by running multiple physical servers as a single one.

DVFS performs scheduling operations to reduce power consumption and increase efficiency [3]. This method integrates a clock into electronic circuits to perform scheduling. The frequency of the clock is synchronized with the supply voltage but with lower power rates. As a result, DVFS runs processors at different combinations of frequencies to reduce the power consumption of the processors.

Nano Data Centers is a distributed computing platform referred to as conventional data centers with low energy consumption. This technique runs a large number of data centers but in smaller sizes; these data centers are distributed geographically and are interconnected, unlike conventional data centers that are large in size and lesser in number. As a result, this technique can reduce power consumption by up to 30%. In addition, it is essential to implement the concept of green cloud computing, in which data centers and servers are remotely controlled [8]. By following the concept of green computing, cloud infrastructure can be more economically viable and efficient.

A depiction of green computing architecture is presented in Fig. 2. An internal structure and components are presented to create an energy-efficient cloud infrastructure. Cloud administrators can manage multiple cloud services through the cloud interfaces.

A. Software Techniques

Leveraging software techniques encompasses two significant techniques: reduced energy consumed by servers and the amount of energy considered by memory. Reducing the amount of energy consumed by servers is achieved by reducing the number of active servers. On the other hand, reducing the energy consumed by memory is realized by reducing the memory nodes running at any given point.

Reduction of Server Consumed Energy

This technique can be achieved by scheduling optimization, a common approach when working on green clouds [9]. The approach is considered the most efficient as compared to hardware optimization. Some parameters here include scalability, consumed resources, and the costs involved. However, the paramount consideration through this approach is determining the most effective way of mapping between requests for both physical servers and VMs. This move will help in reducing the amount of power consumed.

When attempting to achieve energy efficiency in a virtualized cloud environment, a vital consideration is where to place any new VM request in a physical server. The heuristic-based energy-efficient approach is a recent promising proposal. The technique is entirely reliant on the process of analyzing historical data. The technique also leverages the Multiple Correlation Coefficient (MCC) method. MCC entails the measurement of the strength of association that exists among variables. In the process, settling on the server that effectively balances power efficiency and prevents or mitigates SLA violations becomes possible.

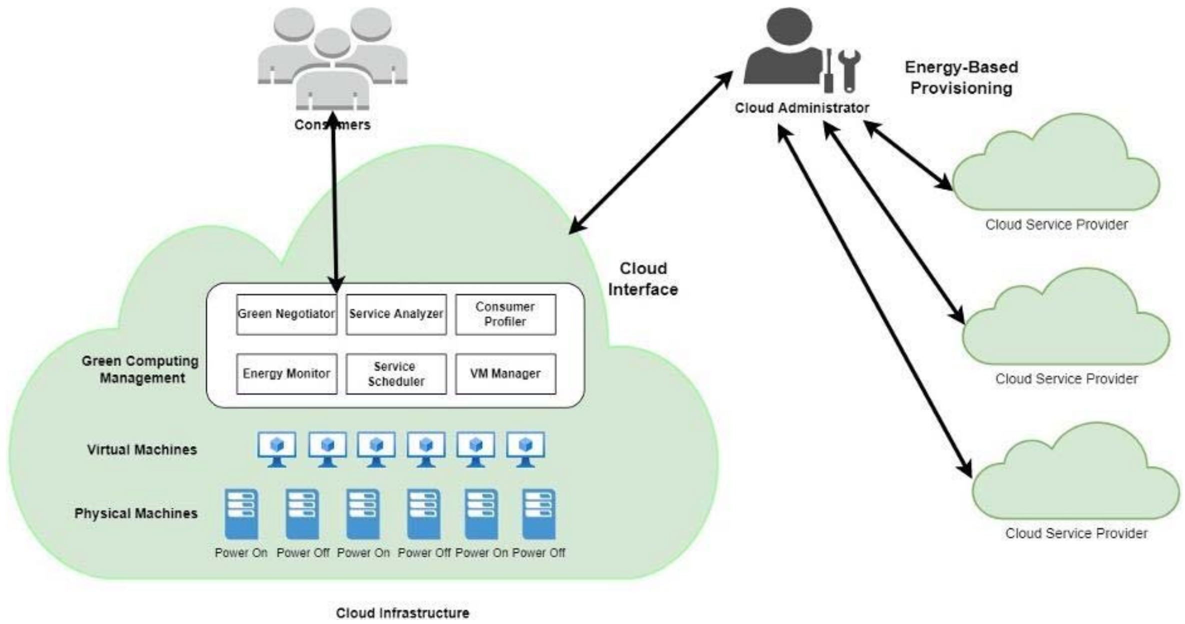

Fig. 2 Cloud administrator and interface

There are higher chances of SLA violation in the data center when the correlation coefficient among all the selected VMs is running in any particular instance. The CloudSim 3.0 toolkit can be utilized in such a scenario to run a simulation, compare the heterogenous physical hosts, and determine the energy consumption level [10]. However, it is critical to note that the algorithm requires information from the hardware aspect of the entire operation. Another approach is motivated by the behavior depicted by ants: the Ant Colony Optimization (ACO) metaheuristic is utilized for VM placement, and the main focus of the ACO meta-heuristic is to reduce the number of active servers significantly. This goal is realized by maximizing the process of computing resources utilization, a perspective that allows more focus on mission-critical processes.

The ACO meta-heuristic computes VM placement through a dynamic approach where the current server load is considered. According to the algorithm, each server starts with the reception of all the VMs, which are then scheduled to servers. Once all the servers (ants) have determined the most effective solutions, those that depict the lowest value for the objective function are considered. Unfortunately, the ACO technique utilizes an unreasonably high number of resources, considering how each server is tasked with developing its solution only for one server with the lowest value to be settled for [10].

Another proposal is the server consolidation algorithm (Sercon), whose focus is also to reduce the amount of energy consumed, especially in the case of homogenous data centers. Sercon also aims to reduce the number of active servers, with most of its attributes being based on First-and-Best-Fit (FF and BF) bin packing problems. The initial step is to sort the servers, during which all the servers are ordered in decreasing order based on each server's loads [11]. Once the servers with the lowest load have been established, all the VMs are considered for migration. The next step is sorting the VMs in decreasing order by considering their weights. Once this phase is completed, each of the VMs is allocated to the heavily loaded servers. As a result, the least loaded server will be left idle; then, all the idle servers are switched off, which automatically translates to reduced energy consumption. The simulation platforms for this process are developed using the .NET 3.5 network, a process that can be used to evaluate the Sercon approach. The downside of Sercon is that it is fully centralized, and the main focus is on homogenous servers only. As a result, the algorithm combats the ability of a server's processor to achieve its optimum capability [11].

VM migration is a technique that can also be embraced to guarantee an optimized scheduling process. The technique is made possible by making a transfer of all the VMs between servers through the network. The approach can achieve the desired efficiency due to its ability to put all VMs on a lower number of physical servers. VM migration and scheduling have been used to manage the number of physical energy servers can consume. The energy-aware scheduling algorithm leverages the Workload-aware Consolidation technique (ESWCT) and focuses on consolidating VMs in the lowest number of servers possible [12]. This objective is achieved by balancing integrated resources such as the network bandwidth, memory, and processor. The integrated resources are often shared among all the users enjoying the services offered by cloud data centers. The most significant consideration in this algorithm is that of the heterogenous workloads and working toward reducing resource consumption.

Reducing Memory-Consumed Energy

Among many other proposals to reduce memory energy consumption, the frontrunner is VM scheduling, especially when dealing with multicore systems. Two scheduling policies characterize the proposal: Biggest Memory Node First (BNF) and Biggest Cover Set First (BCSF). The two policies can make all the scheduling decisions by relying on the existing state of the memory nodes. For example, in reducing the number of memory nodes, the initial steps encompass finding the most extensive access set covered and then scheduling with the corresponding VM. In addition, BNF can schedule individual VMs by considering the popularity of the individual memory nodes. Running a memory power simulator requires MPSim to evaluate the scheduling algorithms. As a result, it is possible to determine the energy consumed by assessing the average waiting time [12].

B. Hardware Techniques

The alternative approach to reducing the amount of energy consumed is the utilization of flexible hardware, which often varies depending on the capability of the individual server. The approach is achieved by controlling the frequencies and voltages associated with each server, which determines the amount of energy consumed by the server. Unfortunately, this approach is quite expensive and also experiences a significant drawback regarding scalability due to the hardware requirements that must be utilized.

As a result, a power-aware scheduling algorithm is employed to implement a DVFS. The technique is applied so that multiple particular processors are involved and deployed to operate at varying frequency and voltage levels. The technique can also select the most appropriate voltage and frequency, guaranteeing the ability to minimize energy consumption. All these are achieved without any form of violation of the SLA. Each of the VMs in such scenarios is allocated to the First Fit Server, where DVFS is then applied to save energy consumption. The outcome is significant compared to the non–power-aware algorithm. This approach is deployed with the CloudSim toolkit [13].

Another approach that can be used in this context factors in SLA depending on the task levels. The alternative approach also provides an avenue for scaling the power voltage alone. The scheduling algorithm for this technique relies on DVS to save energy while ensuring that all scheduled tasks meet the outlined deadlines. Two DVS scheduling policies are considered; time-shared policy and space-shared policy. The simulation of the algorithm is achieved through the GridSim toolkit. The DVS server is also tasked with controlling the supply voltages, a requirement that calls for an additional set of hardware or resources specialized for that role [14].

An alternative approach recommends applying the DVFS technique to establish the optimal frequency for individual scientific flows without necessarily tampering with the overall performance. This approach requires integrating the multi-step heuristic workflow scheduling algorithm referred to as the *Energy-aware Resource Efficient Workflow Scheduling under Deadline Constant* (EARES-D) [15]. The first step entails calculating the estimated earliest completion time for the workflow. The second step is the determination of the optimal frequency required to execute each of the tasks. Finally, the optimal frequency is determined by scaling down the processor frequency under the deadline constraint [16]. Even though all data centers are involved in this technique, the selection of the specific data center is made based on the first and the second step [17].

V. Multi-Cloud Infrastructure Sustainability Practices

Cloud service providers like Amazon Web Services (AWS) are responsible for the sustainability of the cloud, and organizations using multi-cloud are responsible for sustainability in the cloud. Adopting good sustainability practices in the cloud includes using and storing data, automated deployments, scaling, using compute infrastructure, and suitable software design methodologies [18].

Optimizing the compute layer of multi-cloud infrastructure for all kinds of organizations' workloads is the key. It must yield better efficiency for production, test, and development workloads with the least provisioned compute resources and leverage automatic scaling when there is a need for additional capacity. Adopting spot VMs for development workloads will significantly reduce compute resource utilization of cloud infrastructure. The compute workload's power efficiency must be achieved by selecting the correct VM types based on the organization. Building an efficient observability capability for computing, storage, and networking on the cloud will help organizations to track idle resources and maximize utilization [18]. Organizations must follow a good design framework to add metadata tags to each cloud infrastructure resource and build monitoring to provide reports on the usage of these resources.

Metrics for Optimizing Cloud Infrastructure Usage

Determining the amount of energy consumption can only be arrived at by understanding the key parameters that define energy consumption. Three metrics can be used to put in place strategies for optimizing cloud infrastructure:

- CPU utilization: Organizations must adopt constant monitoring of CPU usage, analysis of historic CPU usage, and minimize idle cloud compute resources.
- Storage Utilization: Organizations must constantly monitor free storage, utilized storage, the last time the data on the storage were accessed, and the proximity of the storage infrastructure to the users.
- Network Utilization: Organizations must monitor network bandwidth, data transfer rates, and packets and implement a Content Delivery Network (CDN) service to optimize network utilization.

VI. Design of Greener Cloud Advisor

Greener Cloud Advisor (GCA) is a framework to analyze and process advisory policy for optimizing cloud infrastructure usage. This framework will accept all logs from the cloud monitoring service, analyze historical data for usage, detect anomalies, and auto-generate advisory policy for cloud infrastructure, compute storage, and network. These XML format policies can be used to optimize cloud infrastructure to ensure sustainability in the cloud and the best practices discussed in this article.

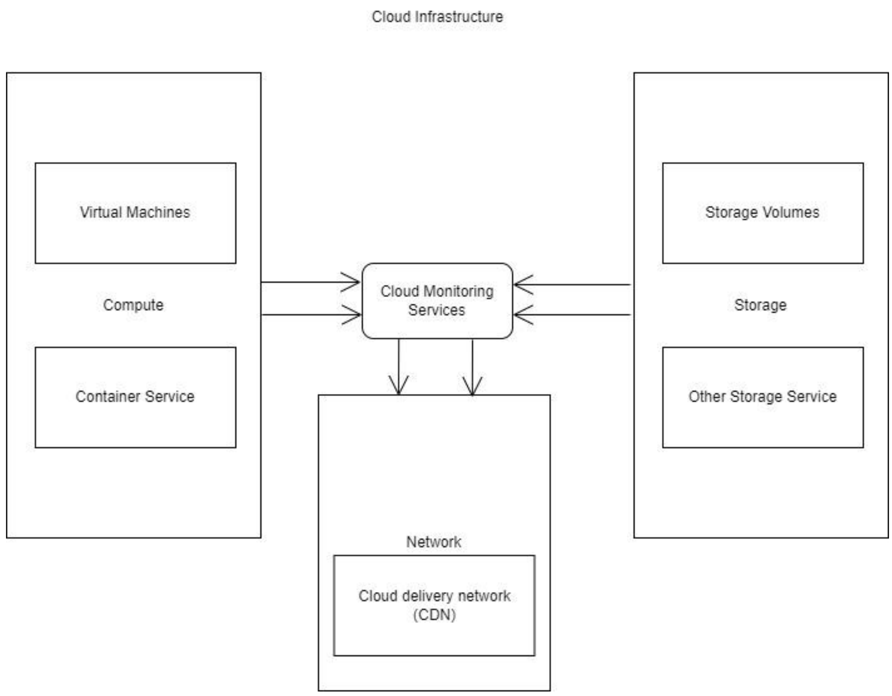

Fig. 3 Cloud computing, storage, network monitoring flow

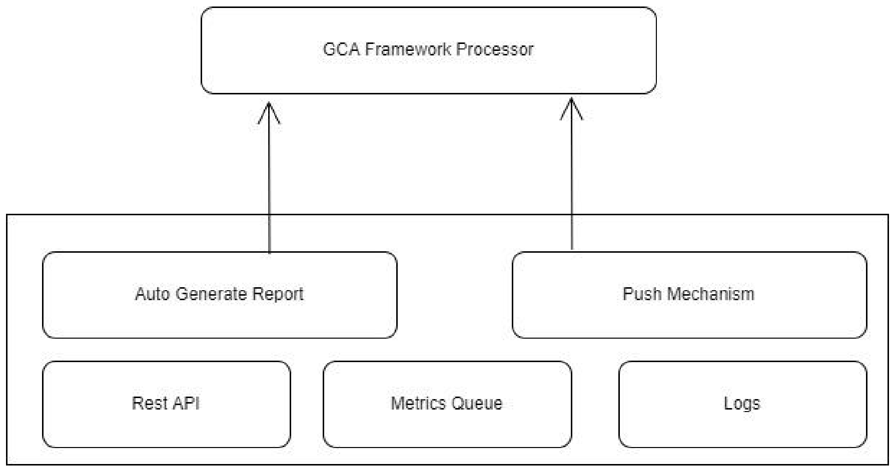

Fig. 4 Core components of GCA

All the cloud infrastructure usage data collected from the cloud monitoring service is timely shipped to a GCA framework. The GCA will auto-generate optimization policies by analyzing usage reports and historical data and detecting anomalies.

The policies will provide detailed implementation steps to adopt optimization rules for cloud infrastructure computing, storage, and networking. This must include advisory for scaling, spot VMs, CDN implementation, the proximity of cloud geographic regions to users, defined provisioning of computing for production workloads, moving data to a compressed or archived state, event-driven design for computing resources, and right-sizing of cloud volumes.

GCA requires a minimum of 1 year of historical data to analyze or detect usage anomalies. The advisory policy is auto-generated by GCA in XML format. Future enhancement and extensions can be implemented to GCA to include a more comprehensive advisory policy.

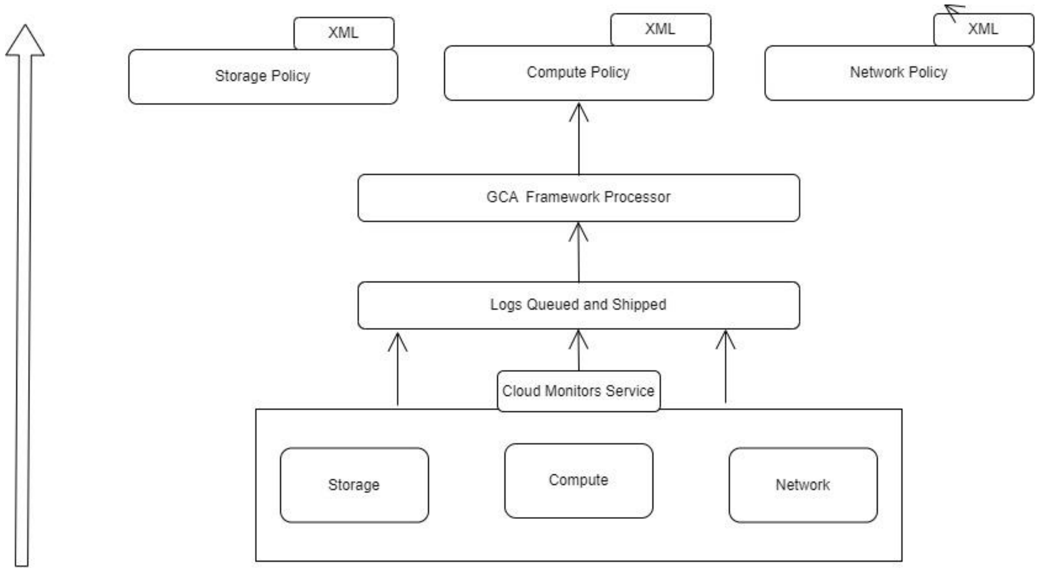

Fig. 5 Policy XML flow

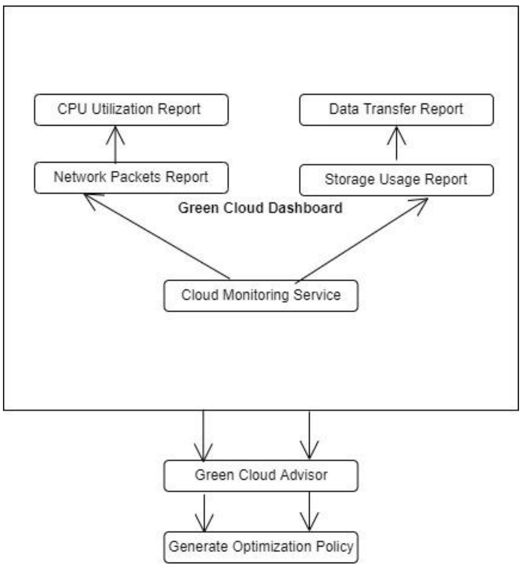

Fig. 6 Green cloud dashboard

Impact of Green Cloud Computing on the Environment

The principal impact of green cloud computing is the minimized carbon footprint, as ever-increasing carbon emissions are the biggest challenge facing the environment today, and the United Nations Environmental Program is among the key organizations regularly delivering warnings about global warming. However, by embracing the green cloud computing concept, businesses can contribute to minimizing their carbon footprints and, by extension, ensure a more sustainable future. In addition, green cloud computing translates to lower power consumption [19]. This is an aspect that is also accompanied by saving on required resources to run cloud computing environments, among other sources of power that would have been misused. Green cloud computing also lowers costs due to reduced expenditures on maintaining data centers. Lower costs can be achieved by leveraging optimization of cooling costs and reducing the number of physical resources, creating more savings in the long run. Faster updates can also be pushed, allowing for a faster way of implementing any changes related to the optimization of data centers, thus saving precious time.

VII. Conclusion

This article discusses how cloud-based infrastructure could reduce energy consumption levels with a particular focus on global warming. We highlight the key point of adopting energy-efficient techniques and the need to adopt green computing. It is evident that over the past few years, cloud computing has significantly contributed to uneconomical energy consumption, especially concerning communication, data processing, and storage. The massive amount of energy currently consumed poses significant threats to the global climate and environment due to data centers' massive carbon emissions [17]. Therefore, green cloud computing should be considered the fundamental approach to supporting the environment. Green computing has massive benefits, including producing environmentally friendly and cost-efficient cloud computing. Essentially, it is the ultimate approach that allows the efficient use of computing resources.

The paper comprehensively covers some techniques that could accelerate the adoption of green cloud computing by breaking down software and hardware techniques that could be integrated into the current data centers. The classifications highlighted in the paper also present multiple comparisons and core implementation techniques. Software optimization and hardware optimization are some key avenues that should be pursued to achieve large-scale green cloud computing adoption. Software optimization is among the most straightforward techniques to implement, considering how it presents the ability to scale and may not even require unique network topologies. However, SLA compliance and energy consumption may negatively affect software optimization.

On the other hand, hardware optimization has been proven to reduce energy consumption while maintaining compliance with SLAs. Unfortunately, hardware optimization is costly and limited by scalability requirements due to special hardware requirements. In conclusion, there are massive opportunities that can still be realized in green computing. Studies conducted over the past decade have paved the way for more opportunities, such as networking techniques that could be used to reduce energy consumption.

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