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Applications of Green Cloud Computing in Energy Efficiency and Environmental Sustainability

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Abstract: *Cloud computing is a highly scalable and cost-effective infrastructure for running HPC, enterprise and Web applications. However, the growing demand of Cloud infrastructure has drastically increased the energy consumption of data centers, which has become a critical issue. Data centers hosting cloud computing applications consume huge amounts of energy, contributing to high operational costs and carbon footprints to the environment. With energy shortages and global climate change leading our concerns these days, the power consumption of data centers has become a key issue. Therefore, we need green cloud computing solutions that can not only save energy, but also reduce operational costs. High energy consumption not only translates to high operational cost, which reduces the profit margin of Cloud providers, but also leads to high carbon emissions which is not environmentally friendly. Hence, energy-efficient solutions are required to minimize the impact of Cloud computing on the environment. In order to design such solutions, deep analysis of Cloud is required with respect to their power efficiency. We need to address various elements of Clouds which contribute to the total energy consumption and how it is addressed in the literature. We also discuss the implication of these solutions for future research directions to enable green Cloud computing. This paper also explains the role of Cloud users in achieving this goal.*
Keywords*: Green cloud, dynamic provisioning, multi-tenancy, Datacenter Efficiency*

I.INTRODUCTION

The ever-increasing demand is handled through large-scale datacenters, which consolidate hundreds and thousands of servers with other infrastructure such as cooling, storage and network systems. Many internet companies such as Google, Amazon, eBay, and Yahoo are operating such huge datacenters around the world.The commercialization of these developments is defined currently as Cloud computing, where computing is delivered as utility on a pay-as-you-go basis. The emergence of Cloud computing is rapidly changing this *ownership-based* approach to *subscription-oriented* approach by providing access to scalable infrastructure and services on-demand. Users can store, access, and share any amount of information in Cloud. Cloud computing also offers enormous amount of compute power to organizations which require processing of tremendous amount of data generated almost every day. According to IDC (International Data Corporation) report , the global IT Cloud services spending is estimated to increase from $16 billion in 2008 to $42 billion in 2012, representing a compound annual growth rate (CAGR) of 27%. Attracted by this growth prospects, Web-based companies (Amazon, eBay, Salesforce.com), hardware vendors (HP, IBM, Cisco), telecom providers (AT&T, Verizon), software firms (EMC/VMware, Oracle/Sun, Microsoft) and others are all investing huge amount of capital in establishing Cloud datacenters.

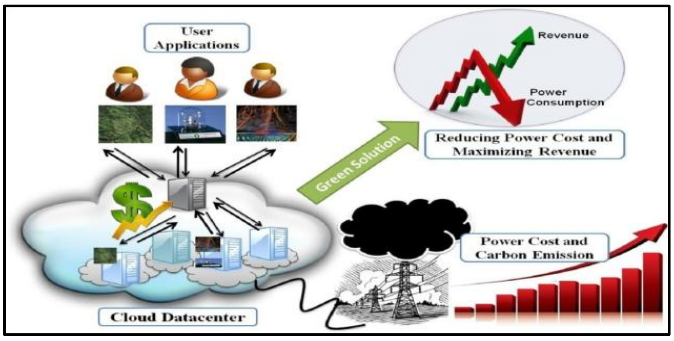

Fig .1 Cloud and Environmental Sustainability

Clouds are essentially virtualized datacenters and applications offered as services on a subscription basis as shown in Figure 1. They require high energy usage for its operation. Today, a typical datacenter with 1000 racks need 10 Megawatt of power to operate , which results in higher operational cost. Thus, for a datacenter, the energy cost is a significant component of its operating and up-front costs. In addition, in April 2007, Gartner estimated that the Information and Communication Technologies (ICT) industry generates about 2% of the total global CO_2 emissions, which is equal to the aviation industry. According to a report published by the European Union, a decrease in emission volume of 15%–30% is required before year 2020 to keep the global temperature increase below 2 ^{0}C. Thus, energy consumption and carbon emission by Cloud infrastructures has become a key environmental concern.

Cloud computing can actually make traditional datacenters more energy efficient by using technologies such as resource virtualization and workload consolidation. Cloud datacenter, on the other hand, can reduce the energy consumed through server consolidation, whereby different workloads can share the same physical host using virtualization and unused servers can be switched off. Even the most efficiently built datacenter with the highest utilization rates will only mitigate, rather than eliminate, harmful CO_2 emissions. The reason given is that Cloud providers are more interested in electricity cost reduction rather than carbon emission. Clearly, none of the cloud datacenter in the table can be called as green.

Cloud computing, being an emerging technology also raises significant questions about its environmental sustainability. Through the use of large shared virtualized datacenters Cloud computing can offer large energy savings. However, Cloud services can also further increase the internet traffic and its growing information database which could decrease such energy savings. A Green Cloud framework for reducing its carbon footprint in wholesome manner without sacrificing the quality of service (performance, responsiveness and availability) offered by the multiple Cloud providers.

II .NEED OF GREEN CLOUD COMPUTING

Modern data centers, operating under the Cloud computing model are hosting a variety of applications ranging from those that run for a few seconds (e.g. serving requests of web applications such as e-commerce and social networks portals with transient workloads) to those that run for longer periods of time (e.g. simulations or large data set processing) on shared hardware platforms. The need to manage multiple applications in a data center creates the challenge of on-demand resource provisioning and allocation in response to time-varying workloads. Normally, data center resources are statically allocated to applications, based on peak load characteristics, in order to maintain isolation and provide performance guarantees. Until recently, high performance has been the sole concern in data center deployments and this demand has been fulfilled without paying much attention to energy consumption .Data centers are not only expensive to maintain, but also unfriendly to the environment. High energy costs and huge carbon footprints are incurred due to massive amounts of electricity needed to power and cool numerous servers hosted in these data centers. Cloud service providers need to adopt measures to ensure that their profit margin is not dramatically reduced due to high energy costs.

Lowering the energy usage of data centers is a challenging and complex issue because computing applications and data are growing so quickly that increasingly larger servers and disks are needed to process them fast enough within the required time period. **Green Cloud computing** is envisioned to achieve not only efficient processing and utilization of computing infrastructure, but also minimize energy consumption. This is essential for ensuring that the future growth of Cloud computing is sustainable. Otherwise, Cloud computing with increasingly pervasive front-end client devices interacting with back-end data centers will cause an enormous escalation of energy usage. To address this problem, data center resources need to be managed in an energy-efficient manner to drive Green Cloud computing. In particular, Cloud resources need to be allocated not only to satisfy QoS requirements specified by users via Service Level Agreements (SLA), but also to reduce energy usage.

III. FEATURES OF CLOUDS ENABLING GREEN COMPUTING

Lower carbon emission is expected in Cloud computing due to highly energy efficient infrastructure and reduction in the IT infrastructure itself by multi-tenancy. The key driver technology for energy efficient Clouds is “Virtualization,” which allows significant improvement in energy efficiency of Cloud providers. Virtualization is the process of presenting a logical grouping or subset of computing resources so that they can be accessed in ways that give benefits over the original configuration. By consolidation of underutilized servers in the form of multiple virtual machines sharing same physical server at higher utilization, companies can gain high savings in the form of space, management, and energy.

1. Dynamic Provisioning: There are various reasons for such over-provisioning: a) it is very difficult to predict the demand at a time; this is particularly true for Web applications and b) to guarantee availability of services and to maintain certain level of service quality to end users. the infrastructure provisioned with a conservative approach results in unutilized resources. Such scenarios can be readily managed by Cloud

infrastructure. The virtual machines in a Cloud infrastructure can be live migrated to another host in case user application requires more resources. Cloud providers monitor and predict the demand and thus allocate resources according to demand. Those applications that require less number of resources can be consolidated on the same server. Thus, datacenters always maintain the active servers according to current demand, which results in low energy consumption than the conservative approach of over-provisioning.

2. Multi-tenancy: Using multi-tenancy approach, Cloud computing infrastructure reduces overall energy usage and associated carbon emissions. The SaaS providers serve multiple companies on same infrastructure and software. This approach is obviously more energy efficient than multiple copies of software installed on different infrastructure. Furthermore, businesses have highly variable demand patterns in general, and hence multi-tenancy on the same server allows the flattening of the overall peak demand which can minimize the need for extra infrastructure. The smaller fluctuation in demand results in better prediction and results in greater energy savings.
3. Server Utilization: In general, on-premise infrastructure run with very low utilization, sometimes it goes down up to 5 to 10 percent of average utilization. Using virtualization technologies, multiple applications can be hosted and executed on the same server in isolation, thus lead to utilization levels up to 70%. Thus, it dramatically reduces the number of active servers. Even though high utilization of servers results in more power consumption, server running at higher utilization can process more workload with similar power usage.
4. Datacenter Efficiency: As already discussed, the power efficiency of datacenters has major impact on the total energy usage of Cloud computing. By using the most energy efficient technologies, Cloud providers can significantly improve the PUE of their datacenters. large Cloud service providers can achieve PUE levels as low as 1.1 to 1.2, which is about 40% more power efficiency than the traditional datacenters. The server design in the form of modular containers, water or air based cooling, or advanced power management through power supply optimization, are all approaches that have significantly improved PUE in datacenters. In addition, Cloud computing allows services to be moved between multiple datacenter which are running with better PUE values. This is achieved by using high speed network, virtualized services and measurement, and monitoring and accounting of datacenter.

IV. TOWARDS ENERGY EFFICIENCY OF CLOUD COMPUTING

4.1 Applications:

SaaS model has changed the way applications and software are distributed and used. More and more companies are switching to SaaS Clouds to minimize their IT cost. Thus, it has become very important to address the energy efficiency at application level itself. However, this layer has received very little attraction since many applications are already on use and most of the new applications are mostly upgraded version of or developed using previously implemented tools.

To achieve energy efficiency at application level, SaaS providers should pay attention in deploying software on right kind of infrastructure which can execute the software most efficiently. This necessitates the research and analysis of trade-off between performance and energy consumption due to execution of software on multiple platforms and hardware. In addition, the energy consumption at the compiler level and code level should be considered by software developers in the design of their future application implementations using various energy-efficient techniques proposed in the literature.

4.2 Cloud Software Stack: Virtualization and Provisioning

In the Cloud stack, most works in the literature address the challenges at the IaaS provider level where research focus is on scheduling and resource management to reduce the amount of active resources executing the workload of user applications. The consolidation of VMs, VM migration, scheduling, demand projection, heat management and temperature-aware allocation, and load balancing are used as basic techniques for minimizing power consumption. As discussed in previous section, virtualization plays an important role in these techniques due to its several features such as consolidation, live migration, and performance isolation. Consolidation helps in managing the trade-off between performance, resource utilization, and energy consumption. Similarly, VM migration allows flexible and dynamic resource management while facilitating fault management and lower maintenance cost. Due to multiple levels of abstractions, it is really hard to maintain deployment data of each virtual machine within a Cloud datacenter. Thus, various indirect load estimation techniques are used for consolidation of VMs.

Although above consolidation methods can reduce the overall number of resources used to serve user applications, the migration and relocation of VMs for matching application demand can impact the QoS service requirements of the user. Since Cloud providers need to satisfy a certain level of service, some work focused on minimizing the energy consumption while reducing the number of SLA violations. Verma proposed an optimization for storage virtualization called Sample-Replicate-Consoidate Mapping (SRCMAP) which enables the energy proportionality for dynamic I/O workloads by consolidating the cumulative workload on a subset of physical volumes proportional to the I/O workload intensity. Gurumurthi proposed intra-disk parallelism on high capacity drives to improve disk bandwidth without increasing power consumption. Soror addressed the problem of optimizing the performance of database management systems by controlling the configurations of the virtual machines in which they run.

Since power is dissipated in Cloud datacenter due to heat generated by the servers, several work also have been proposed for dynamic scheduling of VMs and applications which take into account the thermal states or the heat dissipation in a data centre. The consideration of thermal factor in scheduling also improves the reliability of underline infrastructure.

4.3 Datacenter level: Cooling, Hardware, Network, and Storage

First level is the smart construction of the datacenter and choosing of its location. There are two major factors in that one is energy supply and other is energy efficiency of equipments. Hence, the datacenters are being constructed in such a way that electricity can be generated using renewable sources such as sun and wind. Currently the datacenter location is decided based on their geographical features; climate, fibre-optic connectivity and access to a plentiful supply of affordable energy. Since main concern of Cloud providers is business, energy source is also seen mostly in terms of cost not carbon emissions.

Another area of concern within a datacenter is its cooling system that contributes to almost 1/3 of total energy consumption. two types of approaches are used: air and water based cooling systems. In both approaches, it is necessary that they directly cool the hot equipment rather than entire room area. Thus newer energy efficient cooling systems are proposed based on liquid cooling, nano fluid- cooling systems, and in-server, in-rack, and in-row cooling by companies such as SprayCool. Other than that, the outside temperature/climate can have direct impact on the energy requirement of cooling system. Some systems have been constructed where external cool air is used to remove heat from the datacenter .

Another level at which datacenters power efficiency is addressed is on the deployment of new power efficient servers and processors. Low energy processors can reduce the power usage of IT systems in a great degree. Many new energy efficient server models are available currently in market from vendors such as AMD, Intel, and others; each of them offering good performance/watt system. These server architecture enable slowing down CPU clock speeds (clock gating), or powering off parts of the chips (power gating), if they are idle. Further enhancement in energy saving and increasing computing per watt can be achieved by using multi-core processors.. The use of energy efficient disks such as tiered storage (Solid-State, SATA, SAS) allows better energy efficiency.

The power supply unit is another infrastructure which needs to be designed in an energy efficient manner. Their task is to feed the server resources with power by converting the high-voltage alternating current (AC) from the power grid to a low-voltage direct current (DC) which most of the electric circuits (e.g. computers) require. These circuits inside Power Supply Unit (PSU) inevitably lose some energy in the form of heat, which is dissipated by additional fans inside PSU. The energy efficiency of a PSU mainly depends on its load, number of circuits and other conditions (e.g. temperature). One possible solution offered is to replace all PSUs by ENERGY STAR certified ones. This certificate is given to PSUs which guarantee a minimum 80% efficiency at any power load.

4.4 Monitoring/Metering

To measure the unified efficiency of a datacenter and improve its' performance per-watt, the Green Grid has proposed two specific metrics known as the Power Usage Effectiveness (PUE) and Datacenter Infrastructure Efficiency (DciE) .

- **PUE** = Total Facility Power/IT Equipment Power
- **DciE** = 1/PUE = IT Equipment Power/Total Facility Power x 100%

The Total Facility Power is defined as the power measured at the utility meter that is dedicated solely to the datacenter power. The IT Equipment Power is defined as the power consumed in the management, processing, and storage or routing of data within the datacenter.

4.5. Network Infrastructure

At network level, the energy efficiency is achieved either at the node level (i.e. network interface card) or at the infrastructure level (i.e. switches and routers). The energy efficiency issues in networking is usually referred to as “green networking”, which relates to embedding energy-awareness in the design, in the devices and in the protocols of networks. There are four classes of solutions offered in literature, namely resource consolidation, virtualization, selective connectedness, and proportional computing. Resource consolidation helps in regrouping the under-utilized devices to reduce the global consumption. Similar to consolidation, selective connectedness of devices consists of distributed mechanisms which allow the single pieces of equipment to go idle for some time, as transparently as possible from the rest of the networked devices. The difference between resource consolidation and selective connectedness is that the consolidation applies to resources that are shared within the network infrastructure while selective connectedness allows turning off unused resources at the edge of the network. Virtualization as discussed before allows more than one service to operate on the same piece of hardware, thus improving the hardware utilization. Proportional computing can be applied to a system as a whole, to network protocols, as well as to individual devices and components. Dynamic Voltage Scaling and Adaptive Link Rate are typical examples of proportional computing. Dynamic Voltage Scaling reduces the energy state of the CPU as a function of a system load, while Adaptive Link Rate applies a similar concept to network interfaces, reducing their capacity, and thus their consumption, as a function of the link load.

V. GREEN CLOUD ARCHITECTURE

A unified solution to enable Green Cloud computing is proposed. A Green Cloud framework, which takes into account these goals of provider while curbing the energy consumption of Clouds. The high level view of the green Cloud architecture is given in Fig 2. The goal of this architecture is to make Cloud green from both user and providers perspective.

In the Green Cloud architecture, users submit their Cloud service requests through a new middleware Green Broker that manages the selection of the greenest Cloud provider to serve the users request. A user service request can be of three types i.e., software, platform or infrastructure. The Cloud providers can register their services in the form of green offers to a public directory which is accessed by Green Broker. The green offers consist of green services, pricing and time when it should be accessed for least carbon emission. Green Broker gets the current status of energy parameters for using various Cloud services from Carbon Emission Directory. The Carbon Emission Directory maintains all the data related to energy efficiency of Cloud service. This data may include PUE and cooling efficiency of Cloud datacenter which is providing the service, the network cost and carbon emission rate of electricity, Green Broker 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 buy these services on behalf users.

The Green Cloud framework is designed such that it keeps track of 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". From user side, the Green Broker plays a crucial role in monitoring and selecting the Cloud services based on the user QoS requirements, and ensuring minimum carbon emission for serving a user. In general, a user can use Cloud to access any of these three types of services (SaaS, PaaS, and IaaS), and therefore process of serving them should also be energy efficient. In other words, from the Cloud provider side, each Cloud layer needs to be "Green" conscious.

1)SaaS Level**:** Since SaaS providers mainly offer software installed on their own datacenters or resources from IaaS providers, the SaaS providers need to model and measure energy efficiency of their software design, implementation, and deployment.For serving users, the SaaS provider chooses the datacenters which are not only energy efficient but also near to users. The minimum number of replicas of user□ s confidentialdata should be maintained using energy-efficient storage.

*2)*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 such as JouleSort . It is a software energy efficiency benchmark that measures the energy required to perform an external sort. In addition, platforms itself can be designed to have various code level optimizations which can cooperate with underlying complier in energy efficient execution of applications. Other than application development, Cloud platforms also allow the deployment of user applications on Hybrid Cloud. In this case, to achieve maximum energy efficiency, the platforms profile the application and decide which portion of application or data should be processed in house and in Cloud.

*3)*IaaS level: Providers in this layer plays most crucial role in the success of whole Green Architecture since IaaS level not only offer independent infrastructure services but also support other services offered by Clouds. By using virtualization and consolidation, the energy consumption is further reduced by switching-off unutilized server. Various energy meters and sensors are installed to calculate the current energy efficiency of each IaaS providers and their sites. This information is advertised regularly by Cloud providers in Carbon Emission

Directory. Various green scheduling and resource provisioning policies will ensure minimum energy usage. In addition, the Cloud provider designs various green offers and pricing schemes for providing incentive to users to use their services during off-peak or maximum energy-efficiency hours.

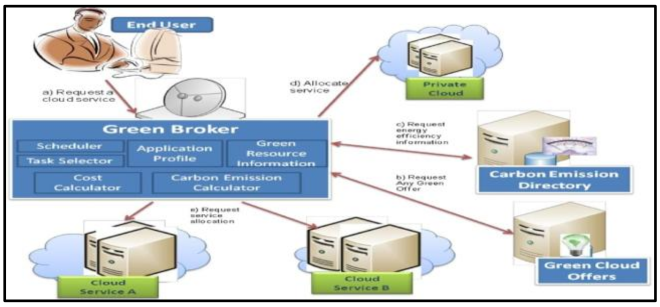

Fig2. Green cloud architecture

VI. GREEN CLOUD ARCHITECTURAL ELEMENTS

The aim of this paper is to addresses the problem of enabling energy-efficient resource allocation, hence leading to Green Cloud computing data centers, to satisfy competing applications' demand for computing services and save energy. Figure shows the high-level architecture for supporting energy-efficient service allocation in Green Cloud computing infrastructure. There are basically four main entities involved:

a) Consumers/Brokers: Cloud consumers or their brokers submit service requests from anywhere in the world to the Cloud. It is important to notice that there can be a difference between Cloud consumers and users of deployed services. For instance, a consumer can be a company deploying a Web application, which presents varying workload according to the number of "users" accessing it.

b) Green Resource Allocator: Acts as the interface between the Cloud infrastructure and consumers. It requires the interaction of the following components to support energy-efficient resource management:

- Green Negotiator: Negotiates with the consumers/brokers to finalize the SLA with specified prices and penalties (for violations of SLA) between the Cloud provider and consumer depending on the consumer's QoS requirements and energy saving schemes. In case of Web applications, for instance, QoS metric can be 95% of requests being served in less than 3 seconds.
- Service Analyser: Interprets and analyses the service requirements of a submitted request before deciding whether to accept or reject it. Hence, it needs the latest load and energy information from VM Manager and Energy Monitor respectively.
- Consumer Profiler: Gathers specific characteristics of consumers so that important consumers can be granted special privileges and prioritised over other consumers.
- Pricing: Decides how service requests are charged to manage the supply and demand of computing resources and facilitate in prioritising service allocations effectively.
- Energy Monitor: Observes and determines which physical machines to power on/off.
- Service Scheduler: Assigns requests to VMs and determines resource entitlements for allocated VMs. It also decides when VMs are to be added or removed to meet demand.
- VM Manager: Keeps track of the availability of VMs and their resource entitlements. It is also in charge of migrating VMs across physical machines.
- Accounting: Maintains the actual usage of resources by requests to compute usage costs. Historical usage information can also be used to improve service allocation decisions.

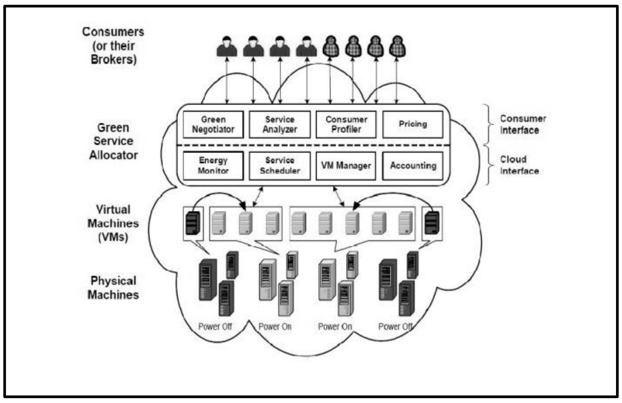

Fig 3.Green Cloud Architectural Elements

- ***VMs*:** Multiple VMs can be dynamically started and stopped on a single physical machine to meet accepted requests, hence providing maximum flexibility to configure various partitions of resources on the same physical machine to different specific requirements of service requests. Multiple VMs can also concurrently run applications based on different operating system environments on a single physical machine. In addition, by dynamically migrating VMs across physical machines, workloads can be consolidated and unused resources can be put on a low-power state, turned off or configured to operate at low-performance levels (e.g., using DVFS) in order to save energy.
- Physical Machines: The underlying physical computing servers provide hardware infrastructure for creating virtualised resources to meet service demands.

VII. MAKING CLOUD MORE GREEN

Mainly three approaches have been tried out to make cloud computing environments more environmental friendly. These approaches have been tried out in the data centres under experimental conditions. The practical application of these methods are still under study. The methods are:

7.1.Dynamic Voltage frequency scaling technique(DVFS):- Every electronic circutory will have an operating clock associated with it. The operatin frequency of this clock is adjusted so that the supply voltage is regulated. Thus, this method heavily depends on the hardware and is not controllabale according to the varying needs. The power savings are also low compared to other approaches. The power savings to cost incurred ratio is also low.

7.2.Resource allocation or virtual machine migration techniques:- In a cloud computing environment,every physical machine hosts a number of virtual machines upon which the applications are run. These virtual machines can be transfered across the hosts according to the varying needs and avaialble resources.The VM migration method focusses on transferring VMs in such a way that the power increase is least. The most power efficient nodes are selected and the VMs are transfered across to them. This method is dealt in detail later.

7.3.Algorithmic approaches:- It has been experimently determined that an ideal server consumes about 70% of the power utilised by a fully utilised server.

Using a neural network predictor,the green scheduling algorithms first estimates required dynamic workload on the servers. Then unnecessary servers are turned off in order to minimize the number of running servers, thus minimizing the energy use at the points of consumption to provide benefits to all other levels. Also,several servers are added to help assure service-level agreement. The bottom line is to protect the environment and to reduce the total cost of ownership while ensuring quality of service.

VIII .OPEN CHALLENGES

In this section, we identify key open problems that can be addressed at the level of management of system resources. Virtualisation technologies, which Cloud computing environments heavily rely on, provide the ability to transfer VMs between physical nodes using live of offline migration. This enables the technique of dynamic consolidation of VMs to a minimal number of nodes according to current resource requirements. As a result, the idle nodes can be switched off or put to a power saving mode (e.g. sleep, hibernate) to reduce total energy consumption by the data center. Despite the energy savings, aggressive consolidation of VMs may lead to a performance degradation and, thus result in SLA violation. Resource management algorithms effectively address the trade-off between energy consumption and performance delivered by the system.

8.1 Energy-aware Dynamic Resource Allocation

Recent developments in virtualisation have resulted in its proliferation of usage across data centers. By supporting the movement of VMs between physical nodes, it enables dynamic migration of VMs according to QoS requirements. When VMs do not use all provided resources, they can be logically resized and consolidated on a minimal number of physical nodes, while idle nodes can be switched off.

Currently,resource allocation in a Cloud data center aims to provide high performance while meeting SLA, without a focus on allocating VMs to minimise energy consumption. To explore both performance and energy efficiency, three crucial issues must be addressed. First, excessive power cycling of a server could reduce its reliability. Second, turning resources off in a dynamic environment is risky from a QoS prospective.Due to the variability of the workload and aggressive consolidation, some VMs may not obtain required resources under peak load, so failing to meet the desired QoS. Third, ensuring SLA brings challenges to accurate application performance management in virtualized environments.

A virtual machine cannot exactly record the timing behaviour of a physical machine. This leads to the timekeeping problems resulting in inaccurate time measurements within the virtual machine, which can lead to incorrect enforcement of SLA. All these issues require effective consolidation policies that can minimise energy consumption without compromising the used-specified QoS requirements.

8.2 QoS-based Resource Selection and Provisioning

Data center resources may deliver different levels of performance to their clients; hence, QoS-aware resource selection plays an important role in Cloud computing. Additionally, Cloud applications can present varying workloads. It is therefore essential to carry out a study of Cloud services and their workloads in order to identify common behaviors, patterns, and explore load forecasting approaches that can potentially lead to more efficient resource provisioning and consequent energy efficiency. Moreover, another goal is to provide the broker (or consumers) with resource-selection and workload-consolidation policies that exploit the trade-offs between performance and energy saving.

8.3 Optimisation of Virtual Network Topologies

In virtualised data centers VMs often communicate between each other, establishing virtual network topologies. However, due to VM migrations or non-optimised allocation, the communicating VMs may end up hosted on logically distant physical nodes providing costly data transfer between each other. If the communicating VMs are allocated to the hosts in different racks or enclosures, the network communication may involve network switches that consume significant amount of power. To eliminate this data transfer overhead and minimise power consumption, it is necessary to observe the communication between VMs and place them on the same or closely located nodes. As migrations consume additional energy and they have a negative impact on the performance, before initiating the migration, the reallocation controller has to ensure that the cost of migration does not exceed the benefit.

8.4 Autonomic Optimisation of Thermal states and Cooling System Operation

A significant part of electrical energy consumed by computing resources is transformed into heat. High temperature leads to a number of problems, such as reduced system reliability and availability, as well as decreased lifetime of devices. In order to keep the system components within their safe operating temperature and prevent failures and crashes, the emitted heat must be dissipated. The new challenges include how and when to reallocate VMs to minimise power drawn by the cooling system, while preserving safe temperature of the resources and minimising migration overhead and performance degradation.

To investigate and develop new thermal management algorithm that monitors thermal state of Physical nodes and reallocate workload from the overheated nodes to other nodes. In this case, the cooling systems of heated nodes can be slowed down, allowing natural power dissipation. We will need to develop an approach that leverages the temperature variations between different workloads, and swap them at an appropriate time to control the temperature. Mechanisms can be effectively used whenever the QoS of hosted applications does not require processors to operate in full capacity. We will extend it for a case where multiple diverse applications with different QoS requirements share the system simultaneously.

8.5 Efficient Consolidation of VMs for Managing Heterogeneous Workloads

Cloud infrastructure services provide users with the ability to provision virtual machines and allocate any kind of applications on them. This leads to the fact that different types of applications (e.g., enterprise, scientific, and social network applications) can be allocated on one physical computer node.The problem is to determine what kind of applications can be allocated to a single host that will provide the most efficient overall usage of the resources. Current approaches to energy efficient consolidation of VMs in data centers do not investigate the problem of combining different types of workload. These approaches usually focus on one particular workload type or do not consider different kinds of applications assuming uniform workload. In contrast to the previous work, we propose an intelligent consolidation of VMs with different workload types. A compute intensive (scientific) application can be effectively combined with a web-application (file server), as the former mostly relies on CPU performance, whereas the latter utilises disk storage and network bandwidth. For the resource providers, optimal allocation of VMs will result in higher utilisation of resources and, therefore, reduced operational costs. End-users will benefit from decreased prices for the resource usage.

IX.CONCLUSION

Cloud computing business potential and contribution to already aggravating carbon emission from ICT, has lead to a series of discussion whether Cloud computing is really green. It is forecasted that the environmental footprint from data centers will triple between 2002 and 2020, which is currently 7.8 billion tons of CO_2 per year. There are reports on Green IT analysis of Clouds and datacenters that show that Cloud computing is "Green", while others show that it will lead to alarming increase in Carbon emission. Even though our Green Cloud framework embeds various features to make Cloud computing much more Green, there are still many technological solutions are required to make it a reality:

- First efforts are required in designing software at various levels (OS, compiler, algorithm and application) that facilitates system wide energy efficiency.
- To enable the green Cloud datacenters, the Cloud providers need to understand and measure existing datacenter power and cooling designs, power consumptions of servers and their cooling requirements, and equipment resource utilization to achieve maximum efficiency
- For designing the holistic solutions in the scheduling and resource provisioning of applications within the datacenter, all the factors such as cooling, network, memory, and CPU should be considered. For instance, consolidation of VMs even though effective technique to minimize overall power usage of datacenter, also raises the issue related to necessary redundancy and placement geo-diversity required to be maintained to fulfill SLAs with users.
- Last but not the least, the responsibility also goes to both providers and customers to make sure that emerging technologies do not bring irreversible changes which can bring threat to the health of human society. Deploy the datacenters near renewable energy sources and maximize the Green energy usage in their already established datacenters. Before adding new technologies such as virtualization, proper analysis of overhead should be done real benefit in terms of energy efficiency.

In conclusion, by simply improving the efficiency of equipment, Cloud computing cannot be claimed to be Green. What is important is to make its usage more carbon efficient both from user and providers perspective. Cloud Providers need to reduce the electricity demand of Clouds and take major steps in using renewable energy sources rather than just looking for cost minimization.

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