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Energy Efficiency of Datacenters and Lower Carbon Emissions in Green Cloud Computing for Environment Sustainability

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ABSTRACT

Green Cloud refers to the prospective environmental benefits that information technology services are delivered via Internet with reliable and easy-accessible atmosphere. The datacenters can consume enormous amount of energy and also emits huge amount of carbons due to large number of cooling equipments, servers and storage systems infrastructure. The data center efficiency is one of the significant factors to enable cloud computing as green by lower energy usage and carbon emissions from business firm. The power efficiency of datacenters has most important impact on the total energy usage of Cloud computing. To achieve the reduction in energy consumption of a datacenter is to calculate the consumed energy in cooling equipments and other metrics with the help of Power Usage Effectiveness (PUE) which can be used to standardized how much energy is beneficially deployed versus how much is spent on other metrics such as power distribution, conditioning equipment, cooling infrastructures, storage and networking subsystems. The PUE of a datacenter is defined as the ratio of the total power consumption of data or switching center to the total power consumption of information technology equipments such as servers, storage and routers. By using the energy efficient technologies such as green broker framework, calculation of cost, energy and carbon emissions, the cloud providers can significantly improve the PUE of their datacenters and hence this approach can preserve the eco-friendly environment.

Introduction

Green computing refers to as environmentally sustainable computing for Information and Communication Technology in delivering the computing requirements as a service to a heterogeneous commune of end-users. Cloud computing is the delivery of on-demand computing resources such as web applications, infrastructure and platform over the Internet on a pay-for-use principle and it enormously emerged in various fields such as scientific, research, academics, business communities, government and private organizations. Green cloud have a tendency to reduce environmental footprint on materials, energy, water, scare resources and it has the limitations in electronic waste from manufacturing to recycling of components. It is the act of optimizing information technology resources by the minimal carbon emissions in datacenters for the efficient energy management.

Cloud computing has few deployment and delivery models to stimulate and process the resources which are described below in brief [2],

In the cloud deployment model, networking, platform, storage, and software infrastructure are provided as services that scale up or down depending on the demand and it have four deployment models which are:

1. Private cloud

The private cloud is used by single organization comprising of multiple consumers (e.g., business units) provisioned by the cloud infrastructure.

It may be owned, managed, and operated by the organization, a third party resource provisioning may exist on or off premises. The company own datacenter and has developed IT infrastructure for security. There are many benefits of performance in computing derived from virtualization and automation techniques. Then only the organization and elected stakeholders have access to operate on a specific private cloud.

2. Public Cloud

The public cloud is used by general public for open use. The third-party cloud service providers can dynamically provisioned pooling on-demand datacenter resources, virtualization to the service requester through web services. The providers allow outsourcing enterprise IT infrastructure solution and the data with its processing environment are not under control of single enterprises and the data has been shared by many cloud consumers.

3. Community Cloud

The community cloud is used by a specific community of consumers from organizations in which the resources are provisioned by cloud infrastructure. It shares mission, security requirements, compliance and policy. The community cloud may be owned, managed, and operated by one or more of the organizations in the community. It requires compliance and interoperability between organizations and their resources including identity management.

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4. Hybrid Cloud

Hybrid cloud infrastructure is a composition of two or more different cloud deployment model such as private cloud, public cloud or community cloud. It is centrally managed and services are provisioned as a single unit and it is surrounded by the secure network to establish the virtual IT solutions. Hybrid cloud is bounded together to enable the portability between data and application. Cloud bursting is one of the best examples of portability for load balancing between clouds.

In Cloud service models, Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) are three fundamental types of services provided by the cloud environment and the functionalities of all these services are as follows,

1. Software as a Service (SaaS)

It is a software distribution delivery model in which service provider licenses an web applications to the service requester for on-demand use of services over the network, typically the Internet and it is accessed using web browsers which deals with web browser security. The framework of service-oriented architecture (SOA) and web services are supported by SaaS on delivering the services. SaaS is implemented to provide the functionality of software for business community at low cost rather than a purchase of licensed software for high cost or adhering complexity in installation. This SaaS model is intended to support multi-tenancy in which concurrent users service allocation are managed at the same time. The benefits of SaaS are rapidly start using innovative business apps by signing in, apps and data are accessible from any connected computer, no data is lost if your computer breaks, as data is in the cloud and the services are able to dynamically scale to usage needs of consumers.

2. Platform as a Service (PaaS)

Platform as a Service (PaaS) provides software resources and development tools through platform in which the applications and services can be hosted on the provider's servers to utilize by the consumers without downloading or installing it. PaaS uses APIs to organize the performance of a server hosting engine and it completes and replicates the execution according to consumer requests on resources. It offers web developers a service that provides an entire software development life cycle management starting from plan, design, build applications, deployment, testing and maintenance. In cloud computing, the virtual machines are act as a medium in the PaaS layer. Cloud malware is the protection of virtual machines against malicious attacks. Machine-to-machine has web applications interaction that is framed by Service Oriented Architecture (SOA) which is the major attack in PaaS service model. The fundamental criterion is to maintain the integrity of applications, strong authentication and validation during the transfer of data across the networking channels in data transmission. PaaS service providers typically secure the platform software stack that includes the runtime engine which holds consumer web applications. The benefits of PaaS are to develop applications and get to market faster, deploy new web applications to the cloud in minutes and it reduces the complexity with middleware as a service.

3. Infrastructure as a Service (IaaS)

IaaS is a single tenant cloud layer where the Cloud service providers provides a pool of resources such as storage, servers, networks, processing power and other computing resources in the form of virtualized systems that are shared with contracted clients at a pay-per-use basis as on-demand services through the Internet. It minimizes the need for huge investment in computing hardwares and provides flexibility as not to purchase internal datacenters. The benefits of IaaS are that it is not necessary to invest in our own hardware, it scales on demand to support dynamic workloads, flexible and innovative services are available on-demand manner. This IaaS service model is the major cause for carbon emissions in data centre which increases the power utilization in computing the resources. The increases in the power usage obviously increase the carbon emission.

Related Works

Virtual consolidation and improved resource utilization create more space, more power and more cooling capacity within the same system environment and tapping into public cloud providers offloads management of those resources from the customer to the service provider. Cloud computing can offer large energy savings by the use of large shared virtualize datacenters.

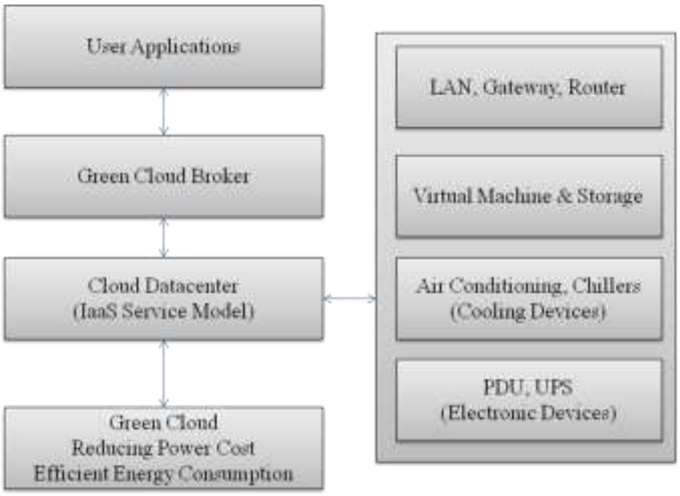

Figure 1. Green cloud Energy Efficiency Usage System Model.

Figure 1 depicts the model of interaction by the end-user applications to the datacenters. The datacenter service utilization is deployed by Infrastructure as a Service framework and it has the processing of networks, cooling devices, electronic devices, servers and storage. Virtual machine provides the functionality of a physical system which is implemented by specialized software and hardware. It has the technology known as a hypervisor, it uses native execution to share and manage hardware in multiple various environments and each one is being isolated from one another but existing on the same physical computer. Cooling devices helps to chill down the processor and consumes energy even with large amount of execution to be carried out in datacenters. The Power Distribution Unit (PDU) and Uninterruptible Power Supplies (UPS) are the devices used to control the electric power in a data center. The floor-mounted and rack-mounted PDUs can be more sophisticated than standard electrical outlets for datacenter equipment, providing data that can be used for Power Usage Effectiveness (PUE) calculations. Rack-mountable PDAs or smart PDUs or intelligent PDUs includes three-phase displays for devices sharing power and also remote management tools that use the Simple Network Management Protocol (SNMP) to provide administrators with the ability to adjust and monitor the demands in power from offsite locations.

The green cloud broker schedules the resources with the help of scheduler, task selector, application profile, green resource information that has carbon emission directory such as the amount of power consumption for the particular resource requested by the consumer, energy cost calculator to calculate the energy utilization to reduce the cost and finally carbon emission calculator component is used for calculating the total amount of carbon-di-oxide emitted for sustaining the green environment. A user request consists of web application, its estimated length in time to serve the resources and requires handling minimum number of resources. These applications are transferred to the green cloud broker who acts as an interface to the cloud infrastructure and web applications on behalf of end-users or consumer which is used to schedule the resources as divided by the set of tasks. The green cloud broker interprets and analyzes the service requirements of a submitted application from the end-user and decides the execution to be taken place in low resource handling virtual machine. The main objective of green cloud broker is to schedule web applications submitted by the consumer in which it reduces CO2 emissions and increases the profit, while the Quality of Service (QoS) requirements of the applications are achieved. As Cloud data centers are located in different geographical regions, they have different CO2 emission rates and energy costs depending on regional constraints. Each datacenter is responsible for updating this information to carbon emission directory for facilitating the energy-efficient scheduling.

Green cloud broker achieves better efficiency in terms of carbon emissions by the following policies employed for scheduling the resources,

a) Greedy Minimum Carbon Emission (GMCE): In this policy, consumer's web applications are assigned to cloud providers in greedy manner based on their carbon emission.

b) Minimum Carbon Emission - Minimum Carbon Emission (MCE-MCE): This is a double greedy policy where web applications are assigned to the Cloud providers with minimum carbon emission due to their datacenter location and carbon emission due to application execution.

c) Greedy Maximum Profit (GMP): In this policy, user applications are assigned in greedy manner to a provider who execute the application fastest and get maximum revenue for their organization.

d) Maximum Profit - Maximum Profit (MP-MP): This is double greedy policy considering profit made by cloud providers and web application finishes by its deadline.

e) Minimizing Carbon Emission and Maximizing Profit (MCE-MP): In this policy, the green cloud broker tries to schedule the applications to those providers which results in minimization of total carbon emission and maximization of profit or revenue for their organization.

The key factors that enable cloud computing to lower energy usage with respect to lower carbon emissions from Information Technology are, Dynamic Provisioning: It is used to reduce wasted computing resources through better comparison of server capacity with actual demand of resources.

Multi-Tenancy: It flattens relative peak loads by serving large numbers of organizations and users on shared infrastructure.

Server Utilization: The operating servers are at higher utilization rates which depend on the number of resources allocated to the datacenters.

Data Center Efficiency: It utilizes advanced data center infrastructure designs that reduce power loss and endow with lower carbon emissions through improved cooling, power conditioning, etc.

In this paper, we dealt with one of the above mentioned key factor as data center efficiency in Infrastructure as a Service model for efficient energy usage in datacenters and reduce the cost of power utilization which increases the revenue for organizations that helps environment to keep green with lower carbon emissions.

Power Usage Effectiveness (PUE) Calculation

It is a measure of how efficiently a computer data center uses energy; specifically, how much energy is used by the computing equipment in contrast to cooling devices. PUE is the ratio of total amount of energy used by a computer data center facility or the effective usage of electrical power to the energy delivered to computing equipment.

$$PUE = \frac{\text{Total Facility Power Load/Energy}}{\text{IT Equipment Power Load/Energy}} \quad (1)$$

- First, Total Facility Power Load is measured at the amount of data centers used to execute the computing resources which includes all the internal components like coolers or chillers, CRAC units, UPS, PDUs, security features, lighting and monitoring equipment required to provide service to the IT equipment load.
- Secondly, measure the IT equipment load. This measurement is determined after all switching and conditioning is performed. The most reliable way to do this is at the power distribution units which should be the total power sent to the racks in the facility.

This determines the efficiency of the running data center. The lower the number is towards 1 which is the better data center efficiency. PUE is generally ranges from 1 to 3 score value which meant of constant energy utilization which does not cause higher carbon emissions.

The reciprocal of PUE expressed as a percentage is known as the Data Centre infrastructure Efficiency - DCiE and is represented by,

$$DCiE\ (\%) = \frac{1}{PUE} \quad (2)$$

Results and Discussion

From the equations (1) and (2), to calculate Power Usage Effectiveness (PUE) based on 2000m^2 Data Hall at 1500 watts/m^2 maximum load density are discussed below,

Input

Total Facility Power Load = 4.427 MW
IT Equipment Power Load = 1.08 MW

Output

Power Usage Effectiveness (PUE) = 3.18
Data Centre infrastructure Efficiency (DCiE) = 24.4 %
Energy Cost (INR) = 5,164,798,807.31 approximately.

After environmental considerations such as cooled chillers, energy saving DC CRAC fans, diesel rotary UPS, static UPS, active lighting control, dynamic smart cooling and solar panels, the following result has been achieved with lower energy cost and it reduces the total power load of the datacenter,

Output

Total Facility Power Load = 2.501 MW
Power Usage Effectiveness (PUE) = 2.32
Data Centre infrastructure Efficiency (DCiE) = 43.2 %
Energy Cost (INR) = 2,918,129,851.11 approximately.

From the above result, a PUE score of 2.32 indicates that the data center demand is nearly two and half times greater than the energy necessary to power the IT equipment. The average data center has a PUE of 2.0 to 2.5. Based on this calculation, one can assume that if a data center has a PUE of 2.0 that for every watt used of IT power, the data center uses an additional watt to cool the site and send power to the IT equipment. The total cost also decreases due to adding the cooling devices and so on which helps to create a sustainable environment by lower carbon emissions (CO_2) from the cloud datacenters in green cloud computing.

Energy efficiency

At the component level, there are two main alternatives to consume less energy for data centers: (a) shutting down hardware components or (b) scaling down hardware performance or (c) downgrading the operating frequency / transmission rate or (d) powering down the entire device or its hardware components in order to conserve energy.

The following two methods are applicable to computing servers and network switches. When applied to the servers, the earlier method is commonly referred to as Dynamic Power Management (DPM) and it results in most of the energy savings environment. This technique will be most efficient if combined with the workload consolidation scheduler which allows maximizing the number of idle servers that can be put into a sleep mode, as the average load of the system often stays below 30% in cloud computing systems [10]. The second method corresponds to the Dynamic Voltage and Frequency Scaling (DVFS) technology [11]. DVFS exploits the relation between power consumption P, supplied voltage V, and operating frequency f as shown in the equation (3):

$$P = V^2 * f \qquad (3)$$

Dynamic Voltage Scaling (DVS) technology was combined with Dynamic Network Shutdown (DNS) to further optimize energy consumption [12].

Setup scenario in GreenCloud Simulator

GreenCloud simulator [13] is a packet-level simulator for energy-aware cloud computing data centers with a cloud communications. It offers a detailed fine-grained modeling of the energy consumed by the data center IT equipment such as computing servers, energy management by hosts initialization, network switches, virtualization and datacenter topology such as topology parameters, network links and task description. GreenCloud can be used to develop novel solutions in resource scheduling, monitoring, workload allocation, optimization of communication protocols and network infrastructures. It is released under the General Public License Agreement and is an extension of the well-known NS2 network simulator [14]. GreenCloud simulator supports for sustainable Eco-Cloud computing environments.

The 20 datacenters are initialized with the task scheduler Heterogeneous Energy-efficient Resource allocation Optimizing Scheduler (HEROS) which is the load balancing algorithm for the consistent process of decision-making. Load balancing in data center networks can be achieved with VM placement algorithms [15] [16]. In the energy management, the hosts and network switches are maintained by the Dynamic Voltage and Frequency Scaling (DVFS) technology with enabling the dynamic shutdown of the idle system. In virtualization, DVFS and virtual machine static configuration are enabled. When it is turned on, a single pool of virtual machines is already deployed before the simulation starts, and the task are sent to these virtual machines. If it turned off, no virtual machines are deployed and tasks are directly sent to servers. Topology created for the datacenter in this simulation system is three-tier high speed network topology.

Table 1. Data Center Topology Parameters and Network links with its Values.

Parameter	Value
Core switches	2
Aggregation switches	4
Access switches per pod	256
Servers per rack	3
Total servers	1536
Core to aggregation	100 Gb/s 0.0033 ms
Aggregation to access	10 Gb/s 0.0033 ms
Access to host	1 Gb/s 0.0033 ms

```
/* herosscheduler.cc */
#include "herosscheduler.h"
#include "dcrack.h"
HerosScheduler::HerosScheduler() : epsilon(0.1){ }
HerosScheduler::~HerosScheduler() { }
double HerosScheduler::calculateScore(ResourceProvider* rp)
{double result = 0;
result = herosTransformation(rp,110,0.90,1.2);
//std::cerr << "Heros transformation result" << result << "\n";
result *= pow(linkLoadFactor(rp->getRootHost()->rack_-
>link_load),2);
//std::cerr << "Final result" << result << "\n";
return result; }
double HerosScheduler::densLoadFactor(double load,double
epsilon)
{return 1/(1+exp(-10*(load-0.5))) - 1/(1+exp((-
10/epsilon)*(load-(1-(epsilon/2))))); }
Double
HerosScheduler::performancePerWatt(ResourceProvider*rp){i
f(rp->getRootHost()->eCurrentConsumption_==0)
{return 0;}
return (rp->getResTypeUtil(Computing)) * rp-
>getTotalCap(Computing) / rp->getRootHost()-
>eCurrentConsumption_ ;
}
double
HerosScheduler::performancePerWattMax(ResourceProvider*
rp){double result = rp->getTotalCap(Computing) / rp-
>getRootHost()->powerModel->getMaxPower();
//std::cerr << "Ppw max: " <<result << "\n";
return result; }
double
HerosScheduler::herosTransformation(ResourceProvider*
rp,double alpha, double beta, double gamma)
{double maxl = rp->getTotalCap(Computing);
// std::cerr << "Ppw current: "
<<performancePerWatt(rp) << "\n";
double result = performancePerWatt(rp);
if(rp->getResTypeUtil(Computing) > beta/2){
result -= gamma * performancePerWatt(rp) *
1/(1+exp( -
(alpha/maxl)*(rp->getResTypeUtil(Computing)*maxl - (beta
* maxl ) ) ));
}return result; }
double HerosScheduler::linkLoadFactor(double load){
return exp(-(pow(2*load,2)));}
TskComAgent*
HerosScheduler::scheduleTask(CloudTask*task,
std::vector<ResourceProvider* > providers){
//std::cerr<< "HEROS is making decision:\n";
vector<ProviderScore> scored_providers_;
```

```
vector <ResourceProvider*>::iterator iter;
for (iter = providers.begin(); iter!=providers.end(); iter++)
{ if ((*iter)->testSchedulingPossibility(task)) {
scored_providers_.push_back(ProviderScore((*iter),calculateS
core((*iter)),linkLoadFactor((*iter)->getRootHost()->rack_-
>link_load))); }    }
if(scored_providers_.empty()){ return NULL;}
else { vector <ProviderScore>::iterator sp;
sort(scored_providers_.begin(),scored_providers_.end(),heros
Comparator);
vector<ProviderScore>::reverse_iterator rsp =
scored_providers_.rbegin();
ProviderScore best = *rsp;
int max_n = 0;
for (; rsp != scored_providers_.rend(); rsp++ ) {
if(!herosComparator((*rsp),best)){ ++max_n; } else {
break; } }
if(max_n!=1){
int selected = (double)rand()/(double)RAND_MAX * max_n
+1;
best = scored_providers_.at
(scored_providers_.size()-selected); }
scored_providers_.clear();
//std::cerr<< "Selected prov: " << best.provider_->id_ <<
"\tScore:" << best.score_ <<"\tSelected task:" << task->id_ <<
"\n";
return best.provider_->getTskComAgent();   } }
bool herosComparator (const ProviderScore &first,const
ProviderScore &second){
if(first.score_ != second.score_){
 return first.score_ < second.score_;}
else {     return
HerosScheduler::performancePerWattMax(first.provider_)*fir
st.comm_potential_<HerosScheduler::
performancePerWattMax(second.provider_)*second.comm_p
otential_; } }
```

The above program "herosscheduler.cc" is that the task scheduler for resource allocation by computational servers which takes care of the workloads in datacenters.

Table 1 shows the values for core and aggregation switches and it has 512 racks with 1536 servers. The bandwidth of the access links connecting computing servers to the top-of-rack switches is 1Gb/s, core to aggregation switches is 100Gb/s and access to aggregation is 10Gb/s, all with 0.0033 ms links.

The number of instructions required to be executed by the task is task size that is 300000 MIPS. The amount of memory required to be allocated during the task execution is 1000000 Pentabyte. The amount of storage that needs to be available during the task execution is 300000 Terabyte. The size of task is 8500 bytes that need to be sent to the server selected for task execution. The task execution deadline is fixed as 5 seconds. The amount of bytes sent out of the data center after successful task execution is 250000 Terabyte.

All these setup in simulation are initialized and after the execution of process, it takes 50.10 minutes for the successful completion of simulation for the above parameters and values. The output are discussed below,

Average Load/Server:	0.2
Datacenter Load:	15.1
Total Tasks:	232599
Average Tasks/Server:	151.4
Tasks Rejected by DC:	0
Tasks Failed by Servers:	46007
Total Energy:	6101.5 W*h
Switch Energy (core):	1033.4 W*h
Switch Energy (agg.):	458.5 W*h
Switch Energy (access):	1375.8 W*h
Server Energy:	3233.8 W*h

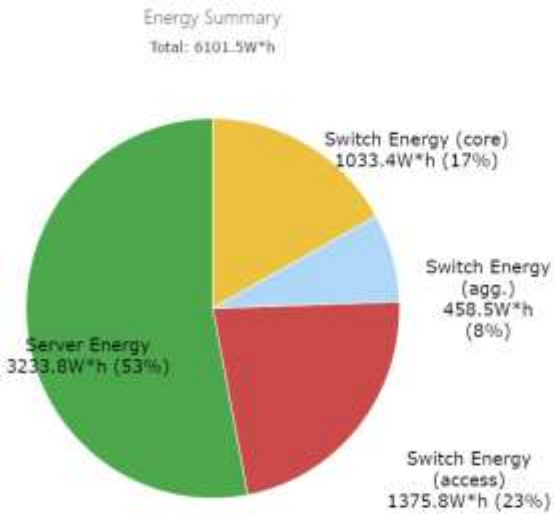

Figure 2. Energy Summary.

Datacenter Computational Load

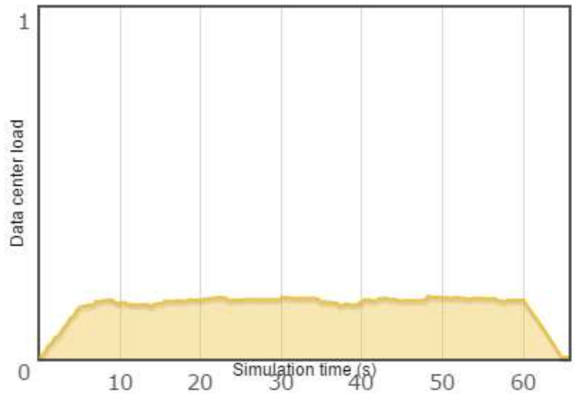

Figure 3. Datacenter Computational Load.

Energy Consumption

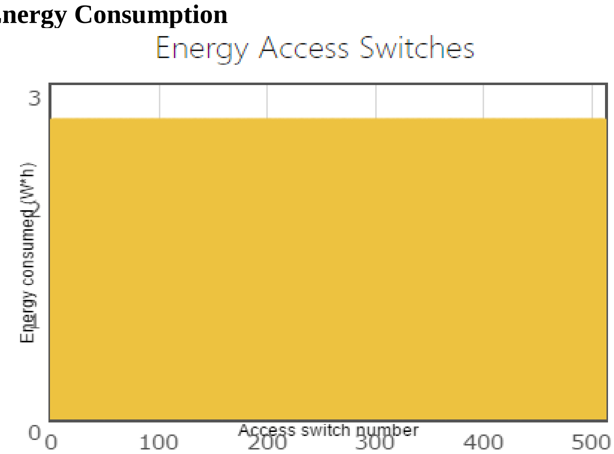

Figure 4.Energy Consumption.

Servers Powers Utilization

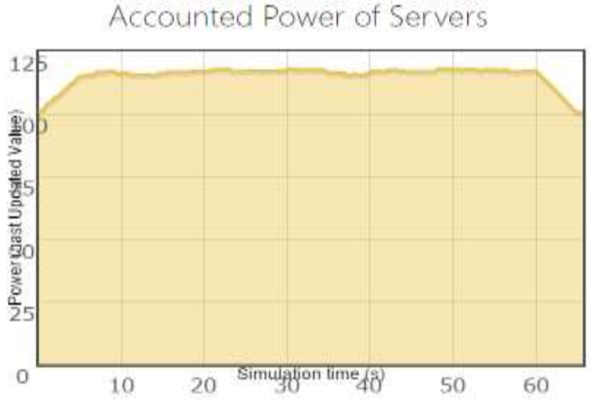

Figure 5. Server powers

The figure 2 depicts the summary of energy consumption by various switches in network links. The graphical representation for datacenter computational load over its simulation time is shown in figure 3. Then the energy consumption (w*h) in the access switches are graphically represented in figure 4. The power of the host by its simulation time is represented graphically in figure 5.

Conclusion

The energy consumption in the datacenters are calculated with the GreenCloud simulation with the help of Energy-efficient Resource allocation Optimizing Scheduler algorithm. The simulation results has been achieved in reducing the energy consumption of a datacenter by the cooling equipments such as cooled chillers, energy saving DC CRAC fans, diesel rotary UPS, static UPS, active lighting control, dynamic smart cooling and solar panels. The Power Usage Effectiveness (PUE) result comparison shows the effectiveness in reducing the total cost and increase the revenue of the organization. By the PUE value, the energy efficiency with the given datacenters was accomplished which helps in lower carbon emissions and protract the green environment.

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