

# **Green Computing Approach to Reduce Power Consumption**

*Thesis submitted in partial fulfillment of the requirements for the award of degree of*

**Master of Engineering**  
in  
**Computer Science and Engineering**

*Submitted By*

**Parminder Kaur**  
**(Roll No. 851232006)**

Under the supervision of

**Dr. Anju Bala**  
Assistant Professor  
(CSED)



COMPUTER SCIENCE AND ENGINEERING DEPARTMENT

THAPAR UNIVERSITY

PATIALA – 147004

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## CERTIFICATE

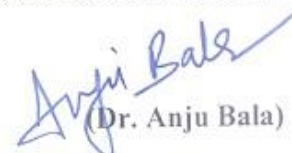
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I hereby certify that the work which is being presented in the thesis entitled, "*Green Computing Approach to Reduce Power Consumption*", in partial fulfillment of the requirements for the award of degree of Master of Engineering in *Computer Science and Engineering* submitted in Computer Science and Engineering Department of Thapar University, Patiala; is an authentic record of my own work carried out under the supervision of *Dr. Anju Bala* and refers other researcher's work which are duly listed in the reference section.

The matter presented in the thesis has not been submitted for award of any other degree of this or any other University.

  
(Parminder Kaur)

This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

  
(Dr. Anju Bala)

Assistant Professor

Thapar University

Patiala

Countersigned by



(Dr. Deepak Garg)


Head of Department

Computer Science and Engineering

Department

Thapar University

Patiala

  
(Dr. S. S. Bhatia)

Dean(Academic Affairs)

Thapar University

Patiala

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**Parminder Kaur**

**851232006**

**MEP (CSE)**

## Abstract

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No doubt that the extensive use of computers and its devices has made our lives easy and comfortable but it has left an ever lasting impact on our environment. This techno-savvy world has led to increase in the huge amount of power consumption which further led to increase in the emission of green house gases like carbon-dioxide. Therefore, energy conservation and power management has become a critical issue of this modern world. And Green Computing addresses this problem of energy conservation by providing green solutions.

Due to rising environmental concerns, the concept of green computing has been in much limelight. Green Computing is the buzzword of today's IT world. It aims to reduce the use of hazardous material, maximize the energy efficiency and promote recyclability of the products. The problems of high power consumption, electronic waste (e-waste) management and energy efficiency has gained much more attention. But the need of saving the energy has become the top priority in the IT world and by implementing green practices these needs can be fulfilled.

In this thesis, an approach for reducing the power consumption of a system had been proposed. This approach can be used to save the power and also help us to use our system and resources in an eco-friendly way. Approach is being supported by an algorithm, flowchart and sequence diagram and for implementing the algorithm CloudSim tool is used.

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# Chapter 1

## Introduction

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This chapter introduces Cloud Computing, its evolution, characteristics and also gives a brief introduction on Green Computing, its need and practices, integrated Green Cloud Architecture, major research issues along with organization of thesis.

### 1.1 Cloud Computing Evolution

The innovative idea of delivering computing resources through a global network was born in the mind of J.C.R. Licklider in 1960. This global network was given the name internet which came into existence in 1969 as a research project at Advanced Research Projects Agency (ARPA) on behalf of the Ministry of Defense, United State (MoD, US) and was initially used for military and scientific purposes, its commercialization started in 1988 with services like e-mail and telnet. So internet is the backbone of all these services which are provided by Cloud Service Provider (CSP). Some experts believe that the concept of Cloud computing is the vision of American computer scientist John McCarthy of MIT (Massachusetts Institute of Technology) given in sixties, he stated that “computation can be delivered as a public utility” [1].

Throughout the life span of 60 years, usage of computers has been evolved spirally from centralized and sharable big size computers in 1970 to decentralize and small personal computers in 1999. Computing power has been distributed. Based on the concept of cost effective sharing, industries in 2010 started to move to distributed center of compact machines for their computational needs. These centers were invisible to the end clients so called Cloud computing [2]. Cloud computing is based on internet computing and is used to provide shared resources, information and software to computers and other devices on demand. These resources are consumed as a service and pay only for what they use. It provides hardware, software and networking services to clients. These services are available to general public, enterprises, corporations and business markets.

Since years cloud computing has evolved in various phases of Grid computing, Utility computing and Software as a Service (SaaS) as shown in Figure 1.1. Grid Computing can be

defined as a collection of distributed computing resources with heterogeneous and non interactive workload from multiple sites which are used collectively to reach a common aim but scope of grid computing is very limited mostly to scientific and research work [3]. Utility computing [4] involves the concept of metered services where accordingly of usage users have to pay, means commercialization of services (e.g. traditional electricity and telephonic services) which can be seen as a prediction made by Leonard Klienrock, one of the scientist of ARPA network, comes to true about the utilization of computer network which was in very beginning condition during his era of 1969 [5]. So the Grid and Utility Computing are the foundation stones of Cloud computing. Third phase of the Cloud computing evolution's is "Software as a Service" (SaaS) which gains popularity in 2010, in which applications and data both reside on vendor's site server, client who want to access the services connects himself with the remote server through internet like social networking. SaaS is only a part of services which is provided by Cloud Services Providers [6]. The application reside on their own data centre and is made available to multiple users over the web. Therefore, Cloud computing is an umbrella term which in itself covers internet based development and services.

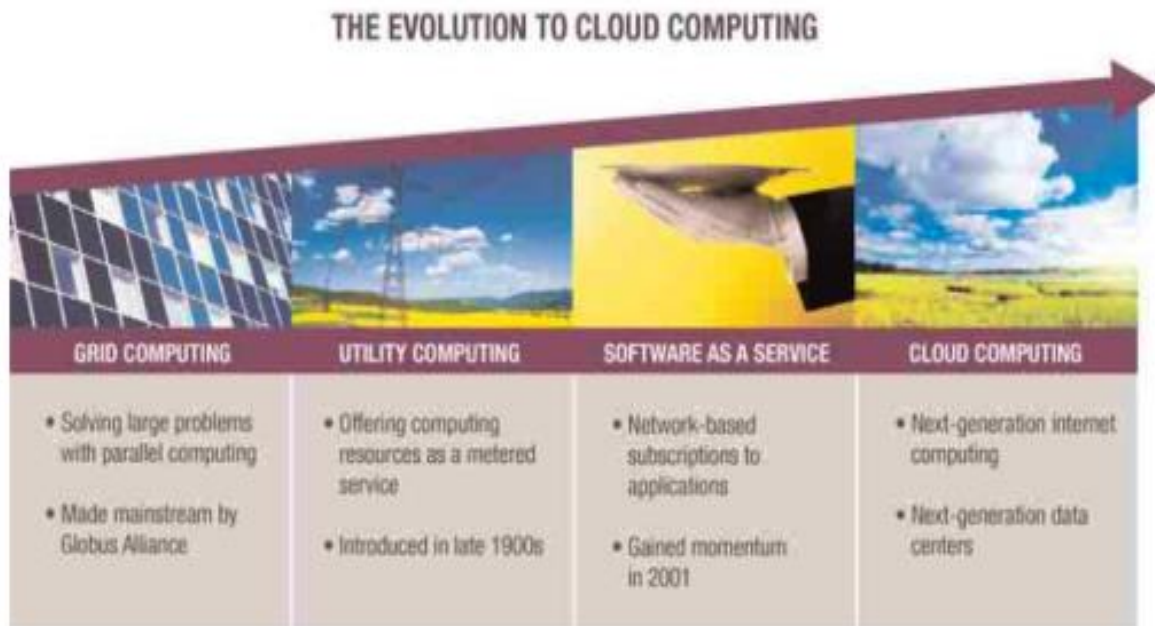


Figure 1.1: Evolution of Cloud computing [7]

From the above discussion we came to know about the evolution of Cloud Computing. And in recent years, Cloud Computing has given birth to a new concept called Green Computing. Green

Computing is the buzzword of today's IT world. The need of the Green Computing arises from the need of the IT companies to save energy. Figure 1.2 depicts the goals of Green Computing. Cloud Computing focus on the efficiency of data computing whereas Green Computing focus on the energy efficiency of a device. It aims to reduce the use of hazardous material, maximize the energy efficiency and promote recyclability of the products. Nowadays, the need of saving the energy has become the top priority in the IT world and by implementing green practices these needs are fulfilled.

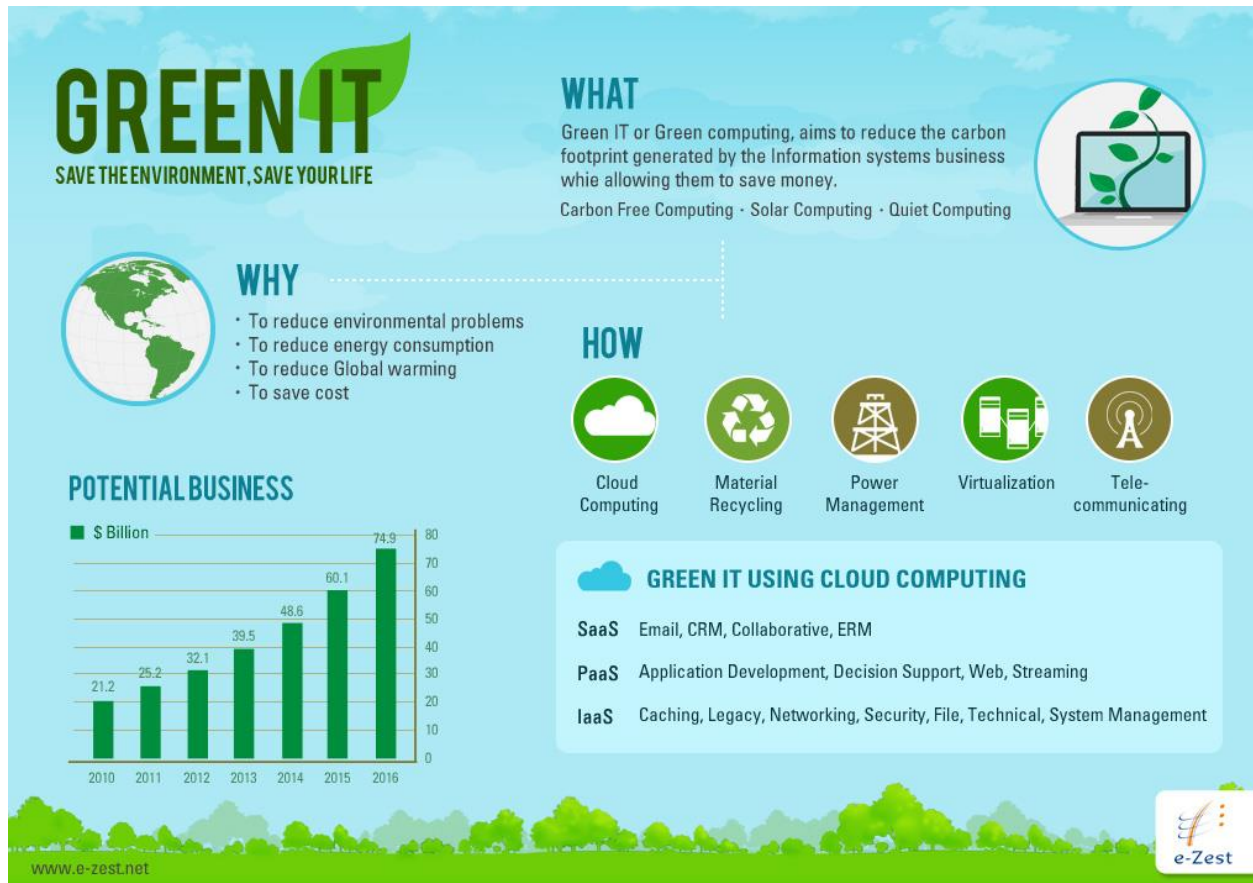


Figure 1.2: Goals of Green Computing [8]

## 1.2 Cloud Computing

Cloud computing has become a buzzword of today. It is not a new concept. It has evolved from various related technologies like Grid computing, utility computing and cluster computing. It is used as a metaphor for the internet. The exact definition of the cloud computing was not known few years back. Various researchers and scientists, e.g. Michael Brown, Gartner, Rajkumar Buyya, and organization like Open Cloud Manifesto have tried their best to frame a standard

definition of Cloud computing but due to different people different views they were failed in doing so. Then in 2011 National Institute of Standards and Technology (NIST) has proposed a standard definition of Cloud computing which covers all the essential characteristics and models based on services and deployments. Table 1.1 shows the different definitions given by many well known scientists and organizations :

Table 1.1: Definitions of Cloud computing

<b>Author/Organization</b>	<b>Definition</b>
Gartner	It is a way of computing by which IT related services are provided to multiple end users using internet [9].
Michael Brown	A data processing infrastructure in which the application software and data reside on server's side that is connected to the internet [10].
Rajkumar Buyya	Cloud is a parallel and distributed system consisting of a collection of interconnected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resources based on service-level agreement established through negotiation between the service provider and consumers [11].
National Institute of Standards and Technology (NIST)	Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This Cloud model is composed of five essential characteristics, three service models, and four deployment models [12].
The Open Cloud Manifesto Consortium	Style of computing by which dynamically scale and provision computing resources in cost effective way so that user can make the most without manage the underlying complexity [13].

### 1.2.1 Characteristics of Cloud Computing

The different characteristics of Cloud computing [14][15][16] are described below: Figure 1.3 give the names of few essential characteristics of Cloud Computing like on-demand service, flexibility, elasticity, scalability etc.

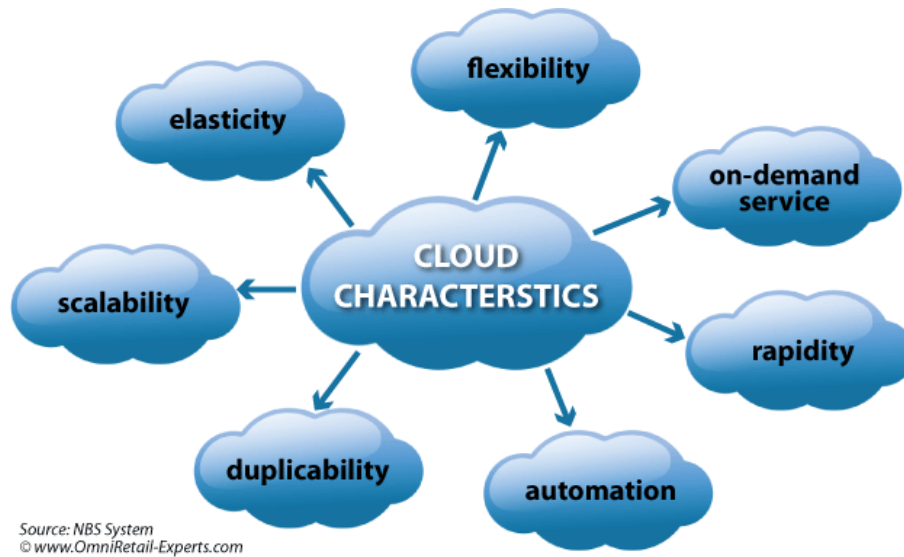


Figure 1.3: Characteristics of Cloud Computing [17]

- **Flexibility:** With Cloud, users can access their files and data from any location and devices e.g. phones, laptops, tablet via internet, called geographic flexibility. Since Cloud Services Providers store user`s data in one central location by which users can easily share their data and work in partnership with others people. Cloud users can buy the suitable storage for storing their files according to their need and eliminate storage capacity planning when no more requirement of it.
- **Reduced Cost:** Cloud offers pay per usage billing model. Startup companies or small business entrepreneurs who don`t have enough man power, technical skills and can`t take risk by investing in infrastructure, easily start their business with no maintenance cost. Cloud users simply rent the infrastructure and technology according to their needs rather than buying it completely. Saved money can be used in other productive works to boost up the company`s output or productivity.
- **Increased Storage:** In the recent time, data is growing exponentially. To handle such a big data in itself is a major issue. Handling of big data covers so many aspects like storage, maintenance, security, and analyzing of big data. Cloud Services Providers offer vast storage for data since Cloud can scale dynamically within minute without decreasing performance.
- **Reliability:** Cloud offers uninterrupted services e.g. no data loss, no delay in services to the end users by using its redundant resources, extremely available, automatically

replicated within its availability zones capability and server end or in transit data encryption.

- **Location Independence:** Users can access their data which resides on unknown server from any locations through internet services using any devices. Users are totally unaware about their data storage and underlying technical complexity of retrieving data. With these features, data and apps can be stored in optimal location for reducing the access time of data, providing fast recovery and highest security to the data.

### 1.2.2 Deployment models of Cloud computing

Cloud services can be deployed in the following ways shown in the Figure 1.4 [18] [19].

- **Public Cloud**

This is one of the common, most cost effective and highly scalable deployment models. All the cloud services and resources are publically available and shared among users through internet. The user pays for the resources used. As the resources are available for all therefore it is highly vulnerable to security attacks. Famous known public clouds are Google App Engine, Microsoft Azure and Amazon web services.

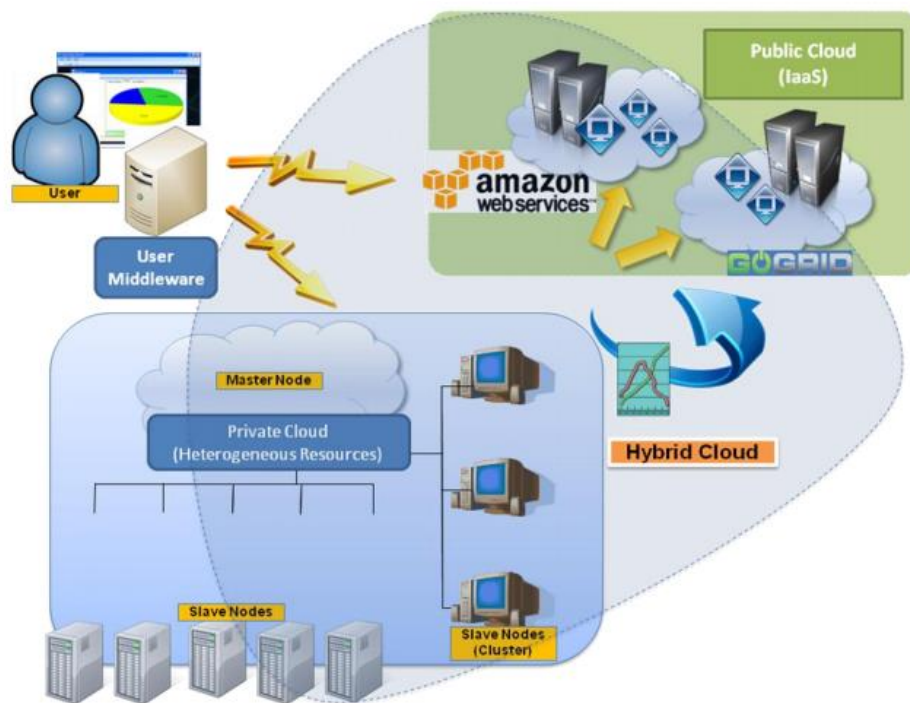


Figure 1.4: Deployment Models of Cloud Computing [20]

- **Private Cloud**

Private Cloud provides access to limited number of authorized users within the organizational premises only. Hence, it is secured from the external threats. Few examples of private cloud are VMware private, CloudBees and Amazon Virtual Private Clouds.

- **Hybrid Cloud**

Hybrid Cloud is the combination of both public and private cloud deployment models. Users have the advantage of both public cloud's scalability and private cloud's security. Services of hybrid cloud are provided by VMware's Vcare and IBM.

### **1.2.3 Green Architecture of Cloud Computing**

The integrated green cloud architecture consists of three layers: the client, a client oriented green cloud middleware and the green broker [23]. The middle layer provides a tool to the client to manage the distribution of tasks with least carbon emission which means least power consumption. The middleware is composed of a user interface application and a windows service. Figure 1.5 shows the green architecture of Cloud Computing. The user interface application will allow the client to specify the required information to the system. The IT manager will input these detail information in the middleware called Green Broker. Similarly, the client PC's specifications, such as storage and processing capacity and power consumption rating, are also registered in the middleware. The green broker, proposed by Buyya R. et al [3], as stated earlier relies on two main components, the Carbon Emission Directory (CED) and Green Cloud Offers (GCO). Green Broker will select the greenest service provider to serve the client's request. Cloud providers register their request in terms of "Green Offers". These Green offers are kept in the public directory and are accessed by the Green Broker. Green offers contain the green services and its pricing and time of access with least carbon emission promise. A carbon emission directory is maintained which contains the data related to the energy efficiency of a service. The function of the Green Broker is to calculate the carbon emission of all the cloud providers wanting to serve the user's request.

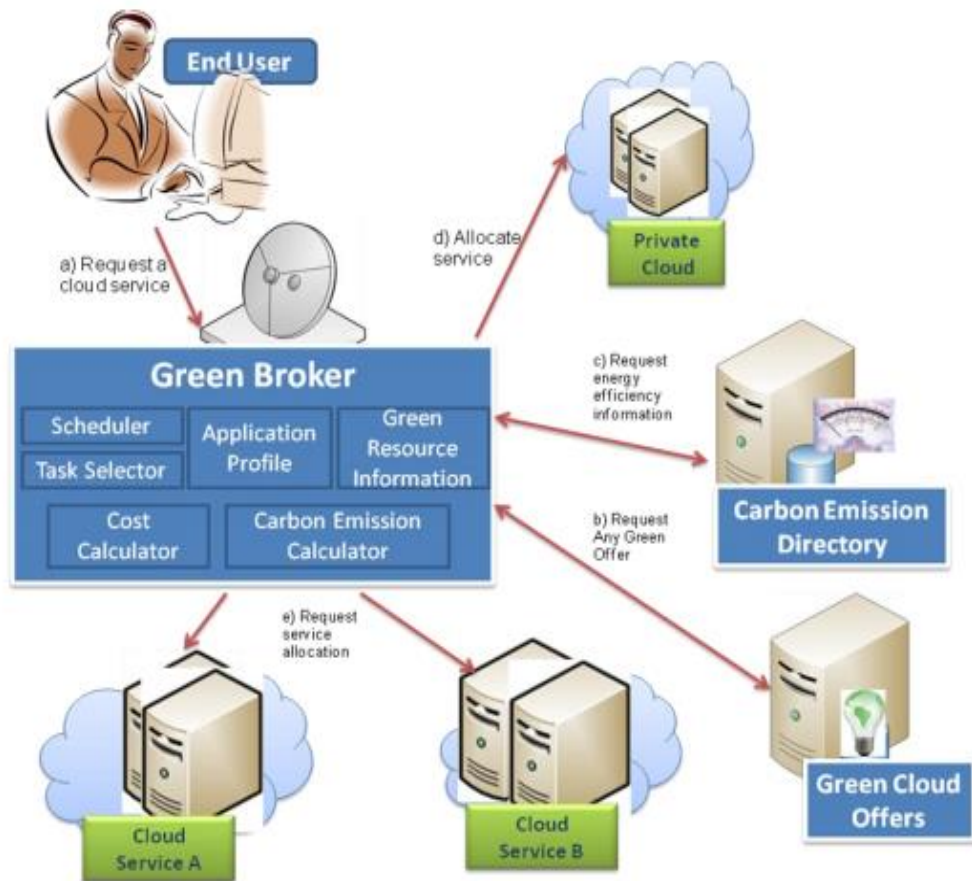


Figure 1.5: Integrated Green Cloud Architecture [23]

After calculating it will select those set of services which will cause least carbon emission and will buy those services on behalf of users. Both the carbon emission directory and the Green offers keep track of the overall energy consumption while serving a user's request. 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 [42].

The second component of the Green Cloud Middleware is a windows service running on the server 1 residing the XML file. The service listens to all jobs executions' requests from any client. If the job is not known to the middleware, a notification is sent to the client and to its job manager. In this situation, the job execution will be performed either on the client's PC or on a server in the company's private cloud. If the job has been registered in the middleware, the latter will read its corresponding execution address from the XML file. For LOCALHOST address, the

notification is sent to the request's sender that will in turn execute the job locally. This notification intelligence is also stored at the client PC so as next time the PC can automatically execute identical job request without communicating with the Middleware. For jobs to be executed in the private cloud, the address configured with the middleware includes the server's name. Job with corresponding execution address to public cloud, the service will communicate with the green broker to decide the best green option offer for the job. The middleware can also communicate with application running on different platform. Thus, the middleware contributes to make better decision for minimizing carbon footprint in cloud architecture (client and CSP side). It is reasonable to assume that the middleware itself, with its processing, has negligible energy consumption. A lightweight middleware development is necessary by employing green software development techniques. In other words, from the Cloud provider side, each Cloud layer needs to be "Green" conscious.

#### 1.2.4 Cloud Computing Green Services

The services provided by Cloud Computing are divided into 3 layers [21] as shown in Figure 1.6 and Table 1.2 describes the services along with their characteristics and green contributions. The role played by these three layers in Green Computing is discussed below:

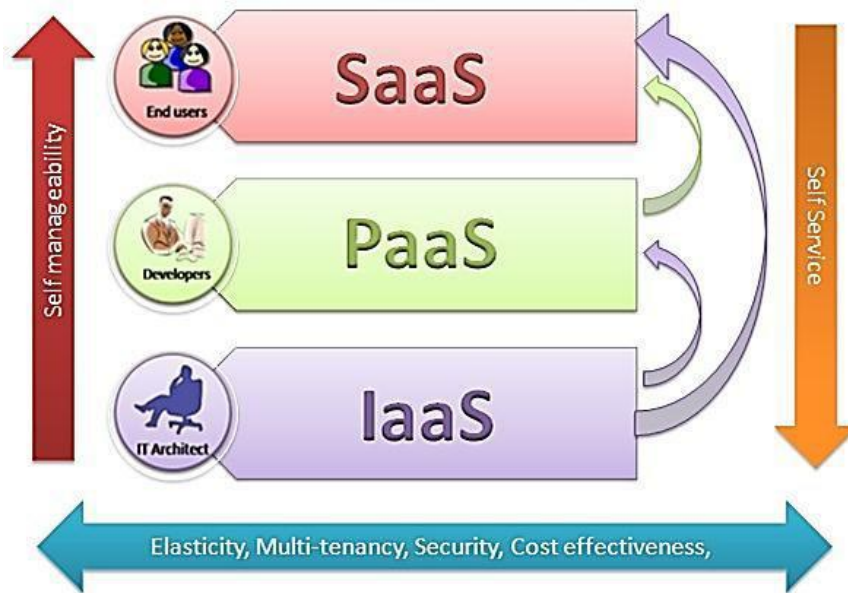


Figure 1.6: Services of Cloud computing [22]

- **Software as a Service (SaaS)**

Cloud users can access complete application or software remotely as a web service on demand using web browser through internet. Today Oracle, Salesforce, Microsoft, Google, Amazon have become the giant Cloud Services Providers which deliver Software as a Service business applications. Gmail is an example of Software as a Service.

For implementing Green Computing, SaaS layer need to measure energy efficiency of software design, implementation and deployment. SaaS must choose those datacenters which are near to users and minimum number of replicas must be maintained of user's data to promote energy efficient storage.

- **Platform as a Service (PaaS)**

Resources are provided to the cloud users through a platform in PaaS. With PaaS, users gain a platform upon which they can easily create and manipulate applications. With PaaS, there is no need to buy the hardware and the underlying software for developing the web application. Google App Engine is one of the common PaaS service provider.

To indulge in Green Computing, inclusion of various energy profiling tools such as JouleSort must be done. It is a software energy efficiency benchmark that measures the energy required to perform an external sort [42].

- **Infrastructure as a Service (IaaS)**

Through IaaS, clients are able to manage the whole system. Clients decide what configuration of operating system, storage size, networking, type of server and security parameters etc they want. Few IaaS examples are Amazon Elastic Compute Cloud (EC2), Secure Storage Service (S3) and GoGrid etc.

This is the most crucial layer for the success of Green Cloud Architecture as it provides latest services for IT and cooling systems so as to provide the energy efficient infrastructure. Various energy meters and sensors are deployed to calculate the current energy efficiency of each IaaS providers and their sites

Table 1.2: Cloud Computing Green Services and their Green contributions

Category	Characteristics	Green Contributions
SaaS	Users are provided with applications that are accessible anywhere and at anytime.	Measure energy efficiency of their software design, implementation, and deployment.
PaaS	Users are provided with a platform for developing applications.	Energy profiling tools are used and platforms designed have the optimized code which uses green compiler for execution of the application.
IaaS	Users are provided with virtualized hardware and storage on top of which they build their infrastructure.	Green scheduling and resource provisioning policies are used to minimize energy usage.

### 1.3 Research Issues in Cloud Computing

Cloud Computing is one of the emerging technology of IT world. There is a lot of space for research work in it. There are some open challenges [24] [25] [26] [27] [28] [29] which need to be addressed to make it more effective in terms of cost, time and security.

- **Automated Service Provisioning**

To minimize the execution cost and maximize the performance, service providers must assign and release the resources automatically. Application Performance Model (APM) is used to make the provisioning of services automatically. It predicts the number of resources required depending upon the future demand. So for the researchers, this is a challenge to make an effective Application Performance Model which will consider all the parameters regarding automated service provisioning.

- **Virtual Machine Migration**

Virtualization is the implementation of the virtual ability to run multiple operating systems parallel on a single physical system. This will reduce the hardware cost which in turn will reduce the power consumption. Less number of systems deployed means less amount of power consumed. It results in less infrastructure energy consumption through resource consolidation and live migration. To move the running virtual machines from one physical server to other is called Virtual

machine migration. It is done to make the Cloud system more fault tolerant. The main research issue is to migrate it completely in time and with full security.

- **Server consolidation**

Server consolidation means to use only the appropriate number of servers which are enough to meet the client's request. By this energy consumption will be reduced and the cost will be saved. Thus, practicing Green Computing. But the researchers need to explore several issues like typify the workloads etc.

- **Fault tolerance**

Fault in term of hardware or software must be tackle carefully without delaying to provide reliable service is a key issue in Cloud computing to be addressed. A survey conducted by Gibson and Schroeder [31] reveals that cloud suffers mainly because of hardware failures occur in hard-disk, memory and processor.

- **Data Security[30][31]**

- (i) Resource Location Issue: In Cloud computing, Cloud users store their data on unknown locations, possibly in other country, and because of this data is not only affected by Cloud Services Provider's policies but also the laws of hosted countries.
- (ii) Multi-Tenancy Issue: Protect user's data from unauthorized users running processes on the same physical server.
- (iii) Authentication: User's data resides on Cloud provider's infrastructure, the data integrity may be violated by others without user's awareness. The
- (iv) proper authenticity of the user's data in this scenario is very essential and hence needs to be assured.

- **Energy Management**

In recent years, energy management is at top priority. The need of all industries is to save energy which led to the birth of Green Computing. The main research issue is the tradeoff between the energy reduction and performance. To manage energy reduction power consumption must be reduced. If power consumption is energy efficient it will save energy. Green Computing approach must be implemented in reducing the power consumption.

Therefore, aim of this thesis is to propose a Green Computing approach for reducing the power consumption which in turn will save the energy. And saving the energy is the top demand nowadays.

#### **1.4 Organization of Thesis**

The rest of the thesis is organized as follows:

Chapter 2 – This chapter describes in detail the literature survey done to study the concept of Green Computing in Cloud computing, concept of energy and power management, existing approaches of power reduction in Cloud.

Chapter 3 – This chapter describes the problem Analysis of the thesis work. It gives the gap analysis and problem statement.

Chapter 4 – This chapter describes in detail the solution of the problem with the help of proposed approach, proposed algorithm, flowchart and sequence diagram.

Chapter 5 – This chapter focus on the implementation details and experimental results, snapshots of the proposed mechanism designed to study the technique.

Chapter 6 – This chapter describes the conclusion, contribution of the work done and future research directions.

## Chapter 2

### Literature Review

This chapter discusses the state of the art and research issues related to Green Computing in Cloud, its need and practices, Power Reduction and Energy Management techniques, existing approaches and comparison among them.

#### 2.1 Green Computing

In today's era, computer has become a basic need of everyone and everybody uses computer and its devices for their own purpose but no one is aware about the harm it is causing to our environment. The concept of Green Computing comes into picture to mitigate this harm by using these devices in an eco-friendly way. "Green computing" represents environmentally responsible way to reduce power and environmental e-waste. Green computing is the practice of using computing resources efficiently. The goals are to reduce the use of hazardous materials, maximize energy efficiency during the product's lifetime, and promote recyclability or biodegradability of defunct products and factory waste [32]. This emerging technology tries to keep our environment green by optimizing the energy consumption. Table 2.1 gives the definition of Green Computing by various authors and organizations.

Table 2.1 Definition of Green Computing

Author/Organization	Definition
San Murugesan	Green Computing include "designing, manufacturing, using, and disposing of computers, servers, and associated subsystems such as monitors, printers, storage devices, and networking and communications systems efficiently and effectively with minimal or no impact on the environment [46]
Energy Star	In 1992, the US Environmental Protection Agency launched Energy Star, a voluntary labeling program which is designed to promote and recognize energy efficiency in monitors, climate control equipment, and other technologies and "Green computing" was probably coined shortly after the Energy Star program began.[10]
Piotr Pazowski	Green computing is the term referring to efficient use of resources in computing and IT/IS infrastructure. Efficiency of green computing emphases on minimizing hazardous environmental impact in conjunction with achieving economic viability and improved system performance.[47]

### 2.1.1 Need of Green Computing

No doubt that the extensive use of computers and its devices has made our lives easy and comfortable but it has left an ever lasting impact on our environment. This techno-savvy world has led to increase in the huge amount of power consumption which further led to increase in the emission of green house gases like carbon-dioxide. Therefore, energy conservation and power management has become a critical issue of this modern world. And Green Computing addresses this problem of energy conservation by providing green solutions. Figure 2.1 represents that why Green Computing is required. This technology is beneficial [32] as it:

- Reduce energy consumption of computing resources during peak operation
- Save energy during idle operation
- Use eco-friendly sources of energy
- Reduce harmful effects of computing resources
- Reduce computing wastes



Figure 2.1 Need of Green Computing [19]

### **2.1.2 Technologies of Green Computing**

The concept of Green Computing is being implemented in the form of clean computing strategies and Green technologies described below [33] [34]

- **Carbon-Free Computing**

This technology refers to reducing the “Carbon Footprints” – the amount of greenhouse gases produced measured in terms of carbon dioxide (CO<sub>2</sub>). Greenhouse gases blanket the earth and are responsible for high global temperature and in turn global warming. Carbon-Free Computing promotes certified carbon free products which emits less amount of CO<sub>2</sub>. Through this, the amount of CO<sub>2</sub> a device will emit into the atmosphere during its operation can be calculated.

- **Solar Computing**

Solar Computing encourages to develop fully solar-powered devices that are non polluting, silent, and highly reliable. Since the maintenance cost of solar cells is negligible, they provide energy at virtually no cost. This technology is increasing rapidly day by day.

- **Energy-Efficient Computing**

This technology provides an energy efficient platform for low power small form factor (SFF) computing devices. It promotes energy efficient processors which produces four times less carbon during their operations and are embedded in solar-powered devices. It helps to meet the environmental protection agency’s energy star guidelines for energy efficient devices.

### **2.2 Role of Green Computing in Cloud**

Clouds play the role of a virtualized datacenters and the applications provided are the services offered by the cloud providers. These services required high amount of energy for their execution. A typical datacenter with 1000 racks need 10 Megawatt of power to operate which results in higher operational cost. It means that for a data center energy cost is the crucial component. In addition, in April 2007, Gartner estimated that the Information and Communication Technologies (ICT) industry generates about 2% of the total global CO<sub>2</sub> emissions, which is equal to the aviation industry [45]. 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 0C. Thus, energy consumption and carbon emission by Cloud infrastructures has become a key environmental concern. Figure 2.2 shows the importance of Green Computing in Cloud. The figure depicts that how the Cloud Computing led to increase carbon emission and high power cost but if Green practices are followed then it can reduce the power cost and can maximize the revenue. Green Computing provides the “Green Solutions” to these harmful problems. By implementing the technologies such as resource virtualization and workload consolidation, the datacenters can become much more energy efficient.

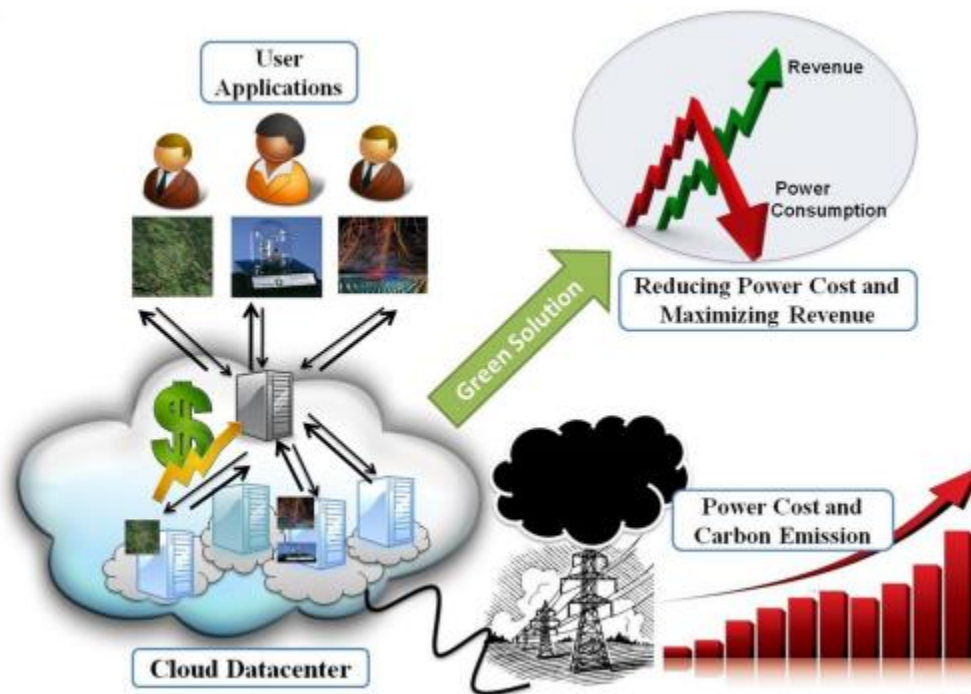


Figure 2.2 Role of Green Computing in cloud[45]

The traditional data centers running Web applications are often provisioned to handle sporadic peak loads, which can result in low resource utilization and wastage of energy. 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 [45]. Thus Green Computing must be encouraged and it's provided “Green Solutions” must be implemented to make our environment clean and green.

### **2.3 Existing Energy Saving Approaches for Green Cloud computing**

Some techniques of saving the energy are discussed below [35] [36]. Existing approaches for saving energy include use of Dynamic Voltage/Frequency Scaling (DVFS) [14] and use of virtualization techniques for better resource utilization. Various researchers have put many efforts to reduce the energy consumption in clouds and data centers.

- **Calculating energy consumption by considering single task as a unit**

An energy consumption model is presented which analyze and calculate the total energy consumption in cloud environments based on different runtime tasks. Here energy consumption model is taken as an input and energy consumed by each task is the output. It identifies the relationship between running tasks and energy consumed by them.

- **Scheduling of workloads**

In this approach workload across the servers is scheduled in terms of cost to operate and to improve efficiency. It uses queuing theory principles and an exponential relationship was found between power cost and server utilization. It was also proposed that optimal efficiency can be achieved by maintaining server configuration with respect to the required utilization for handling the recommended workload.

- **Efficient server allocation**

An algorithm is designed for efficiently managing the network resources by allocating workload. The packet loss is minimized and hence efficiency is achieved. Servers are selected to process the workloads at speed matching the packet arrival rate. Optimal performance is achieved at a point in server speed which is the critical point as it cannot be achieved at less or more speed.

Further energy saving strategies exists in aspects of hardware, software technology, virtual machine manager and network environment.

- **Hardware Energy saving design**

It includes energy saving strategy for computer architecture and also analyzes the hardware temperatures. Research for a new and highly efficient computer architecture is going on which can reduce the power consumption. Heterogeneous computer refers to the multi-processor system composed by a plurality of relatively independent processors of the different types. It can get better power consumption ratio, using general purpose processor as the main control unit and dedicated processor as accelerator structure. At the

same time, high-performance computer system built with low power consumption processor also can reduce the system energy consumption effectively [36]. Intelligent temperature control mechanism for processor, storage hardware to reduce consumption is being promoted.

- **Energy saving strategy for software technology**

It includes the strategy for compilers and software power which focus on source program structure level. Advanced compiler optimization technique can greatly improve the performance of the compiler and reduce the energy consumption. Compiling technology research not only can optimize the application efficiency, but also analysis the behaviors of application program to minimum system or processor operation energy consumption. Zhao Rongcai, put forward a model and method, which can reduce the execution frequency to reduce the power consumption in multithreading system structure. It can reduce power consumption effectively [36].

## **2.4 Power Management and Analyzing Power Consumption**

Many well known experts and scientists have done researches on power consumption and have proposed some approaches which could make the power consumption efficient. Much more research work is going in this area to reduce the harmful impact to save the environment. Many have worked on reducing the power consumption not only in a device but also in cloud data centers via migrating the virtual machines.

- Ms S Gowri and Mr V. Harikrishnan [37] have analyzed the power consumed by different hardware parts of a computer device with different configuration and had provide a solution for less power consumption. The analysis is being done with the help of a software “Local Cooling”. Various power options of a laptop and desktop is being compared and best practices are to be followed to reduce the power consumption. Energy consumption data of different components like CPU, display device etc have been analyzed. Minimum configuration will require minimum power consumption.
- Aqueel Mahesri and Vibhore Vardhan [38] have given the power consumption breakdown of a modern laptop. The power usage of key components in an IBM ThinkPad R40 laptop is measured. The power consumption is measured for different types of

workloads. System power is dominated by CPU power in case of CPU intensive workloads. Authors have found that by reducing the backlight brightness, the system power will be reduced significantly. Authors have also observed the OS differences in power consumption. Component wise power consumption breakdown was required to analyze the system power consumption. Laptop power consumption is workload dependent.

- Mona Arjmandi et al. [39] proposed the reduction of power consumption in cloud data centers via dynamic migration of virtual machines. Overloaded host is recognized and then eliminated from the host list to improve the host performance. The model proposed will reduce the power consumption and that too with limited number of migrations. But the SLA breach has increased through it.
- Patil Vijay M et al. [40] described the energy consumption in wireless sensor networks. If a node energy goes below a level then that node is being replaced by another node dynamically. This way energy consumption is reduced in cluster as the wireless network contains so many clusters. A novel algorithm is introduced which select the cluster head from multiple sensor nodes in the same cluster. It improves the lifetime activation of wireless sensor network.
- Arthi T and shahul Hamead H [41] have analyzed the existing energy consumption model for various types of services in cloud computing environment and presented a new energy aware provisioning approach. Pre processed data about the service usage of cloud is being used for initiating the live migration.
- Anton Beloglazov et al. [43] have defined an architectural framework for energy efficient Cloud Computing. They have proposed an energy-aware allocation method which will allocate data center resources to client applications in a way that improves energy efficiency of the data center, while delivering Quality of Service (QoS). A survey in energy-efficient computing was also done and proposed: (a) architectural principles for energy-efficient management of Clouds; (b) energy-efficient resource allocation policies and scheduling algorithms considering QoS expectations and power usage characteristics

of the devices; and (c) a number of open research challenges, addressing which can bring substantial benefits to both resource providers and consumers.

## 2.5 Comparative study of various Energy Efficient Algorithms

Many researchers have proposed various approaches and algorithms for achieving Green Cloud Computing. These energy efficient algorithms, their parameters and basic techniques are discussed below in Table 2.2

Table 2.2 Comparative study of various energy efficient algorithms

<b>Title of paper</b>	<b>Basic Technique Used</b>	<b>Parameters used</b>	<b>Tool used</b>
Energy Efficient Computing in Wireless Sensor Network: Application of Green Computing Approach[40]	Clustering	Number of clusters, Energy Level of cluster Head	CloudSim
Energy Aware Cloud Service Provisioning Approach for Green Computing environment[41]	Energy aware model for automatic VM migration	Pre processed data about the service usage, number of clients and server utilization	Not implemented
Adaptive energy-efficient scheduling algorithm for parallel tasks on homogeneous clusters	Dynamic voltage scaling(DVS)	Number of duplicated tasks, task dependencies	Not implemented
Energy Efficient VM scheduling for Cloud Data centers: Exact allocation and migration algorithms[46]	VM migration and scheduling	Number of servers and VM's, power consumption of server and VMs	Java
Energy and Carbon Efficient Placement of Virtual Machines in Distributed Cloud Data Centers[47]	VM allocation	Data center's power usage and VM requests	CloudSim

## **2.6 Conclusion**

Various approaches of energy management have been analyzed and the main parameter recognized is the power consumption. If the power consumption in an approach is reduced then the approach will become an energy efficient approach which is our main goal.

## Chapter 3

### Problem Analysis

Previous chapter analyzed various techniques for solving the issues related to high Power Consumption in Cloud. This chapter focuses on the gaps in literature review.

### 3.1 Gap Analysis

Nowadays it is impossible to imagine the world without computers or laptops. The growing demand of these techno-savvy products has led to increased power consumption. This huge amount of power consumed has an impact on the environment. And to provide the solution to these environment related issues Green Computing comes into picture. Many researchers have proposed various methods for reducing the power consumption.

Based on the literature survey there are various techniques (as shown in Table 3.1), which manage these issues of huge power consumption but these are not efficient as some power reduction algorithm must be proposed. The analysis of the total energy consumed by the system is also required.

Table 3.1 Different Power Reduction Techniques in Cloud

Title of Paper (year)	Reduction of Power consumption technique used	Limitations
Energy Saving Approaches for Green Cloud Computing (2014)	Scheduling of Workloads and Efficient server allocation	Approaches used are without virtualization. Virtualization can help better in utilizing the resources in cloud.
Energy Aware Cloud Service Provisioning Approach for Green Computing Environment	Proposed an energy awareness model for server provisioning	Model need to be scaled further to include more number of entities.
Reduction of Power Consumption in Cloud Data Centers via Dynamic Migration of Virtual Machines(2015)	Virtual Machine Migration	SLA breach has increased
Power Consumption Breakdown on a Modern Laptop	Power measured using an Agilent oscilloscope and current probes	Accuracy of Results is limited to several factors
Green Computing: Analyzing Power Consumption using Local Cooling(2014)	Local Cooling software is used to analyze the data on power consumption	Major techniques like Virtualization and migration not implemented. Whole dependency on local cooling software.
The Strategic Plan Founded on Efficiency of Using Green Computing Techniques in Data Centers(2014)	Consolidation	New solutions proposed are not implemented

A Green Computing based Architecture Comparison and Analysis(2010)	A model is proposed to analyze energy consumption of a software architecture	Little work is done on the analysis on the amount of energy consumed by the CPU.
Energy Efficient Computing in Wireless Sensor Network: Application of Green Computing Approach (2014)	Clustering	Algorithm need to enhance to include load balancing among cluster heads.

### 3.2 Problem Statement

Due to rising environmental concerns, the concept of green computing has been in much limelight. The problems of high power consumption, electronic waste (e-waste) management and energy efficiency has gained much more attention. The need of the hour for all the industries and corporates using cloud is to save energy by reducing the huge amount of power consumption. Reduction in power consumption has become the top priority for all.

The aim of this thesis work is to propose a Green Computing Approach for reducing the power consumption of a system which will be using the concepts of both virtualization and live migration. This approach can be used to save the power and also help us to use our system and resources in an eco-friendly way. Our proposed approach is a way of practicing the sustainable Green Computing which will reduce the harm caused to the environment by saving huge amount of power and energy.

### 3.3 Objectives

- (i) To study the existing approaches of reduction of power consumption and energy saving strategies in Cloud.
- (ii) To develop an algorithm to reduce the power consumption of a system so as to practice Green Computing.
- (iii) To verify and validate the proposed Algorithm.

### 3.4 Conclusion

Problem has been formulated based on Gap Analysis which addresses the issue of power management in Cloud. A Green approach will be proposed to save the power and to use our system and resources in an eco-friendly way.

## Chapter 4

### Proposed Method

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This chapter discusses about how the problem stated in previous chapter can be solved with the help of proposed algorithm, flowchart and sequence diagram.

#### 4.1 Solution in Detail

The solution to the problem (reduction of power consumption in Cloud) has been explained through an algorithm of the proposed approach along with its flowchart. This section explains the solution in detail with the formula representation of the total energy of the system and proposed algorithm, its flowchart and sequence diagram of the proposed method

##### 4.1.1 Basic Concept involved in Proposed Approach

One of the major goals of green computing is reduction in power consumption. The growing demand of computers, laptops and other resources has led to huge amount of power consumption. The large amount of power consumed has an adverse affect on our environment. Therefore, there is a dire need to use our systems and resources in an eco-friendly way. Our proposed approach is a way of practicing the sustainable green computing which will reduce the harm caused to the environment by saving huge amount of power.

For low power consumption Green Computing use the concepts of virtualization and live migration. Virtualization is the implementation of the virtual ability to run multiple operating systems parallel on a single physical system. This will reduce the hardware cost which in turn will reduce the power consumption. Less number of systems deployed means less amount of power consumed. It results in less infrastructure energy consumption through resource consolidation and live migration. Live migration is the process of allowing virtual machines to be moved transparently from one physical machine to another, while virtual machines are continuously running [48]. In this article live migration concept will be used to migrate the data from virtual machine to the host machine which after migration will put the virtual machine in sleep mode. Thus, reducing the power consumption.

In this approach the power consumed has been classified into static and dynamic power of the system.

- **Static Power**

Static power is defined as the power consumed when the system is in idle state. Static means the power a system will always draw no matter what kind of operation is being performed.

- **Dynamic Power**

Dynamic power is the power consumed when the system is in active state. It will vary depending upon the task being run.

#### 4.1.2 Formula Representation of the Total Energy

Total energy consumed by the system will depend on both static energy and dynamic energy.

Static energy is represented as in equation (1)

$$\text{Static energy (S)} = \text{VIcos}_\phi \text{T} \quad (1)$$

where  $\text{VIcos}_\phi$  is the static power of the system and T denotes the time during which the system is on.

Dynamic energy is being represented as below in equation (2)

$$\text{Dynamic energy (D)} = \sum_{i=1}^n \text{pi ti} \quad (2)$$

where  $\text{pi}$  represents the dynamic power. As the dynamic power depends on various factors like amount of work load, task scheduling, number of instructions required to complete a task it will be difficult to anticipate it. Hence it will be measured using joulemeter software. Here  $t$  represents the execution time of the task and  $i$  denotes the number of tasks executed.

**Total energy (TE) = Static energy (S) + dynamic energy (D)**

$$\text{TE} = \text{VIcos}_\phi \text{T} + \sum_{i=1}^n \text{pi ti} \quad (3)$$

When the system is idle means no task is being performed then the system will draw only the static power in form of  $\text{VIcos}_\phi$  (single phase). When the systems will run the tasks then dynamic

power will be measured which will depend on the type of tasks being run. Total power of the system is addition of both static and dynamic power. The total power measured between the range of 15-60watt is considered as an energy efficient power. If the total power is above this threshold value then the live migration of the data from virtual machine to the host machine will be done. The task which was running on virtual machine will now be transmitted onto the host machine. Thus, turning the dynamic power of the virtual machine to null. Hence the total power of the system being consumed will be reduced.

#### 4.1.3Proposed Algorithm

Below described is the proposed algorithm for reducing the power consumption of the system.

##### Power reduction algorithm

1. Start
2. Declare variables  $w_1, w_2, w_3, PT, PS, PD, PD_h, PS_h, PD_{vm}$   
//  $w_1, w_2, w_3$  - Reading of power  
//  $PT$  – Total Power ,  $PD$  – Dynamic Power ,  $PS$  – Static Power  
//  $PD_h$  – Dynamic power of host ,  $PD_{vm}$  – Dynamic power of VM  
//  $PS_h$  – Static power of host
3. Read  $w_1$  from wattmeter.
4.  $PS \leftarrow w_1$  // VM and host are idle
5. Read  $w_2$  from wattmeter.
6.  $PT \leftarrow w_2$  // VM and host are in active state
7. If ( $PT > \text{Threshold value}$  )  
Migrate data from VM to host machine.  
 $PS = PS_h$   
 $PD = PD_h + PD_{vm}$   
Read  $w_3$  from wattmeter. // VM in sleep mode and host in active  
 $PT \leftarrow w_3$   
 $PT = PS + PD$   
Else  
If( $PT < \text{Threshold value}$ )  
Display “Power consumed is energy efficient”.
8. If still  $PT$  more than threshold value then  
Display “System overloaded”.
9. Stop

#### 4.1.4 Design of the Proposed Approach

The flow diagram of the approach has been presented in figure 4.1. The detailed step by step procedure has been described in which the power is measured when the system is in idle as well as in active state. During the idle state only static power will be drawn and during active state both static and dynamic power will be drawn. If the total power becomes more than the threshold value then next step being performed will be the migration of data from virtual machine to host machine. Migrating the data will result the virtual machine to go into sleep mode. Thus reducing the total power as the sleep mode feature consumes only 3-15 watt of power. Dynamic power of the virtual machine will also become null as no task is being run which will add to the power reduction of the system. Hence the overall total power of the system will be reduced.

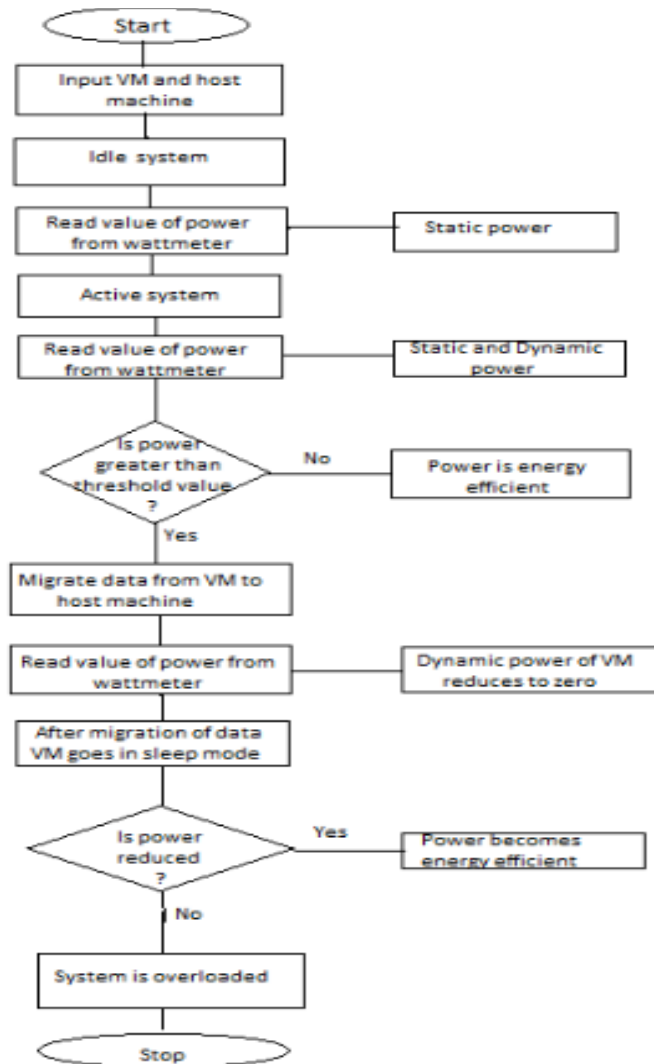


Figure 4.1 represents the flowchart diagram of the approach

### 4.1.5 Sequence Diagram

Figure 4.2 provides the detailed sequence diagram of the above approach. User will read the power when the system will be idle and in active state. During idle state it will draw only the static power and in active state it will draw both static and dynamic power.

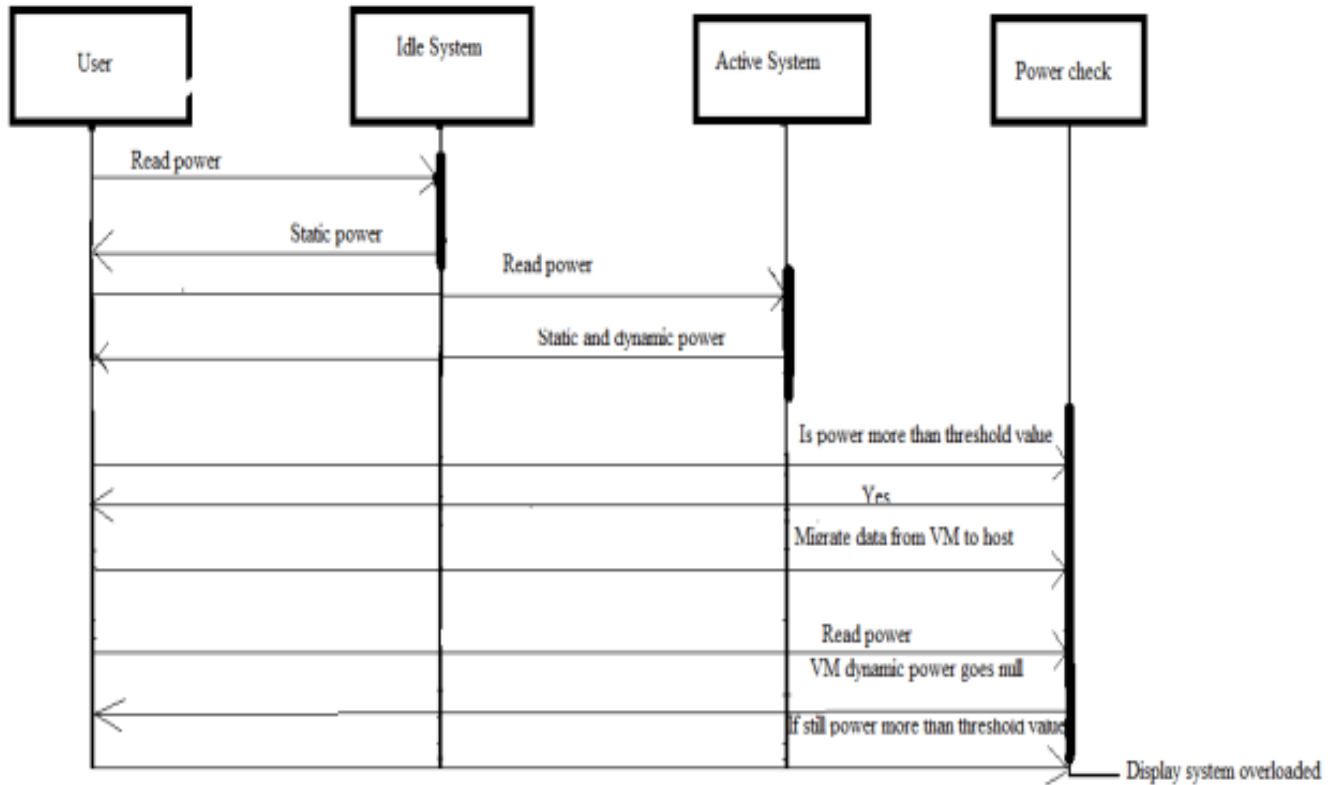


Figure 4.2 represents the sequence diagram of the proposed approach

### 4.1.6 Pictorial Representation

Figure 4.3 pictorially describes the proposed approach. Here in this figure a virtualized system is attached with the digital wattmeter. When the virtualized system is idle it will draw only the static power. When the different virtual machines will run different tasks it will draw both static and dynamic power. If this total power becomes more than the threshold power then we need to migrate the data from VM machine to host machine and after migration VM machine will go into sleep mode. The static power of VM machine thus gets eliminated and dynamic power is transferred or gets add up with the dynamic power of

the host machine. VM machine in sleep mode will draw only 0-2watt of power. Thus reducing the overall power consumption of the system.

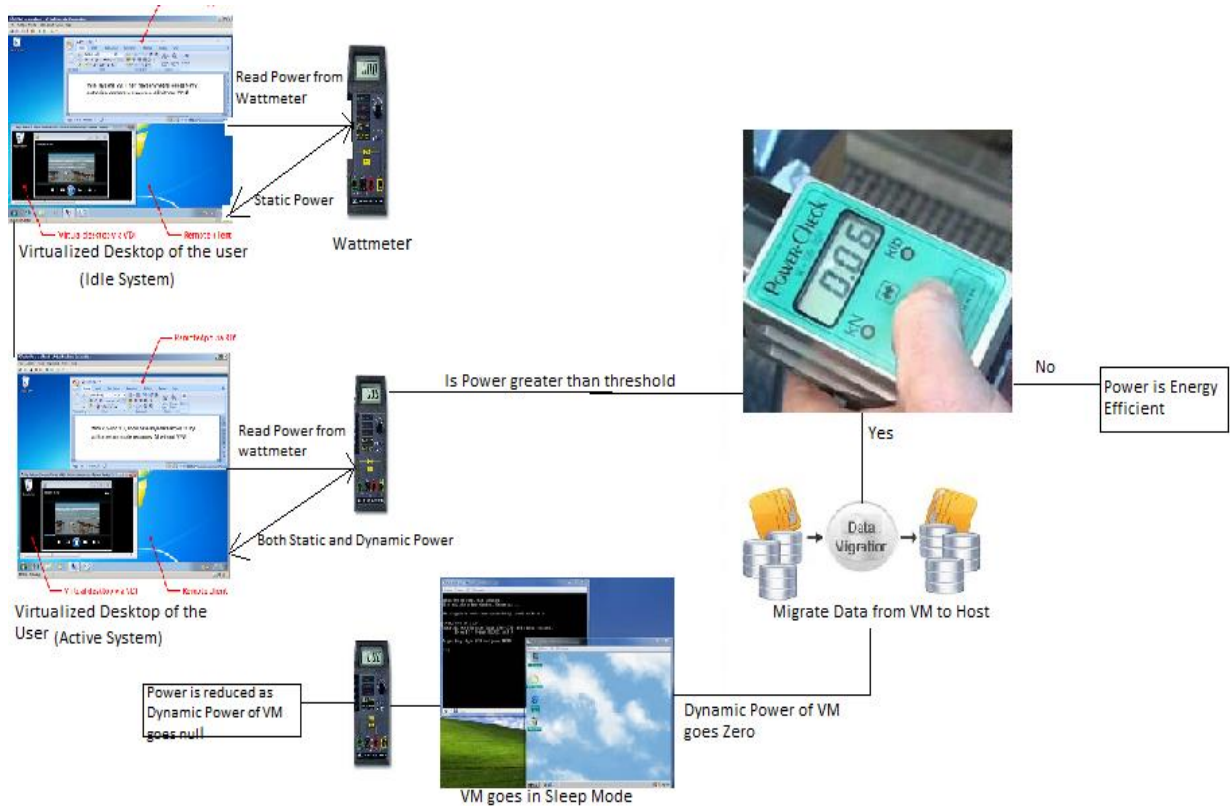


Figure 4.3 Pictorially representation of the proposed approach

## 4.2 Conclusion

In this chapter, a power reduction algorithm is introduced which reduces the power consumption of the system. This approach has classified the total power of the system into static and dynamic power. By using virtualization and live migration the dynamic power factor of the virtual machine will become null. The virtual machine will go into sleep mode. Thus, reducing the total power consumed by the system.

This chapter focuses on tools for showing the power reduction, implementation of the proposed power reduction algorithm on CloudSim and experimental results of static and dynamic power along with comparisons done between formulas of power consumption.

#### 5.1 Tools for Setting up Simulation Environment

Cloud applications have different type of configuration and deployment requirements. Various tools required to show the simulation for reducing the power consumption of the system on Cloud is described below.

- CloudSim

The main purpose of CloudSim is to provide a simulation framework that enables modeling, simulation, and experimentation of emerging Cloud computing infrastructures and application services, allowing its users to focus on specific system design issues that they want to investigate, without getting concerned about the low level details related to Cloud-based infrastructures and services[49].

##### **CloudSim Architecture**

Figure 5.1 shows the layered architecture of the CloudSim framework. Initially CloudSim uses SimJava but currently this SimJava layer has been removed as it does not supported some advanced operations. CloudSim provides simulation for virtualized data centers and for managing the interfaces for VM's. At this layer implementations are done programmatically. A cloud is allocated to a set of VM's which will execute the applications. This layer also facilitates the functioning that a Cloud application developer is able to perform complex workload profiling and application performance study. The top layer is the user code and tells about the number of VM machines and their configurations. With the help of CloudSim , researchers are able to perform tests based on specific configurations and it also allows to develop the best practices considering all the aspects related to Cloud Computing. To work on it the basic requirement is the knowledge of java concepts and language.

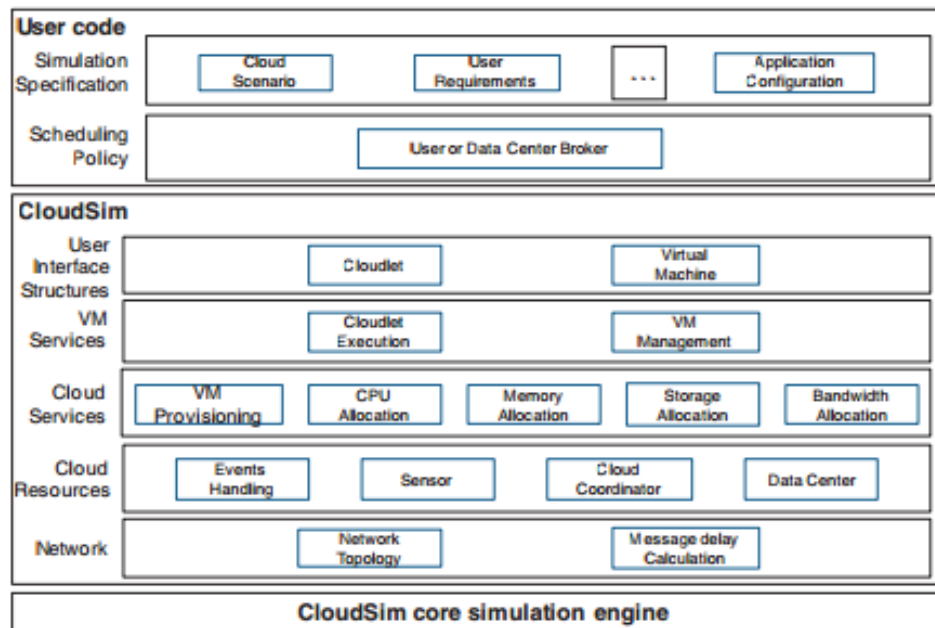


Figure 5.1 Layered CLOUDSim Architecture [50]

## 5.2 Implementation of the Proposed Algorithm

Mechanism for reducing the power consumption of a system on cloud has been simulated using CloudSim tool and implementation of the proposed algorithm is shown as snapshots in Figure 5.2. It shows the CloudSim workspace and the proposed algorithm written in form of a program in Java.

```

package sim;

public class CloudSim {
    int w1,w2,w3,PT,PS,PD,DH,DVM;
    /*
    PS is the Static Power of the system
    PD is the Dynamic Power of the system
    PT is the Total Power of the system
    */
}

public static void main(String[] args) {
    CloudSim csim=new CloudSim();
    final int threshold=60;

    /*
    W1 is the power when VM and Host are idle
    */
    csim.setW1(20);

    /*
    W2 is the power when VM and Host are active
    */
    csim.setW2(30);

    /*
    W3 is the power after migration
    */
    csim.setW3(55);

    csim.setPS(csim.getW1());
    csim.setPD(csim.getW2());
    csim.setPT((csim.getPS()+csim.getPD()));
}

```

The screenshot shows the Eclipse IDE with the following components:

- Package Explorer:** Shows the project structure with 'sim' package and 'CloudSim.java' file.
- Editor:** Displays the Java code for the 'CloudSim' class and its 'main' method.
- Outline:** Lists the variables and methods defined in the class, such as 'w1', 'w2', 'w3', 'PT', 'PS', 'PD', 'DH', 'DVM', and various 'get' and 'set' methods.
- Bottom Bar:** Shows the status bar with 'Writable', 'Smart Insert', and '10:9'.

Figure 5.2 Algorithm implemented in CloudSim

Below in figure 5.3 the output is shown of the case when the power consumed is already energy efficient. Here the total power consumed is below the threshold value i.e below 60watt. Hence no migration of data is required.

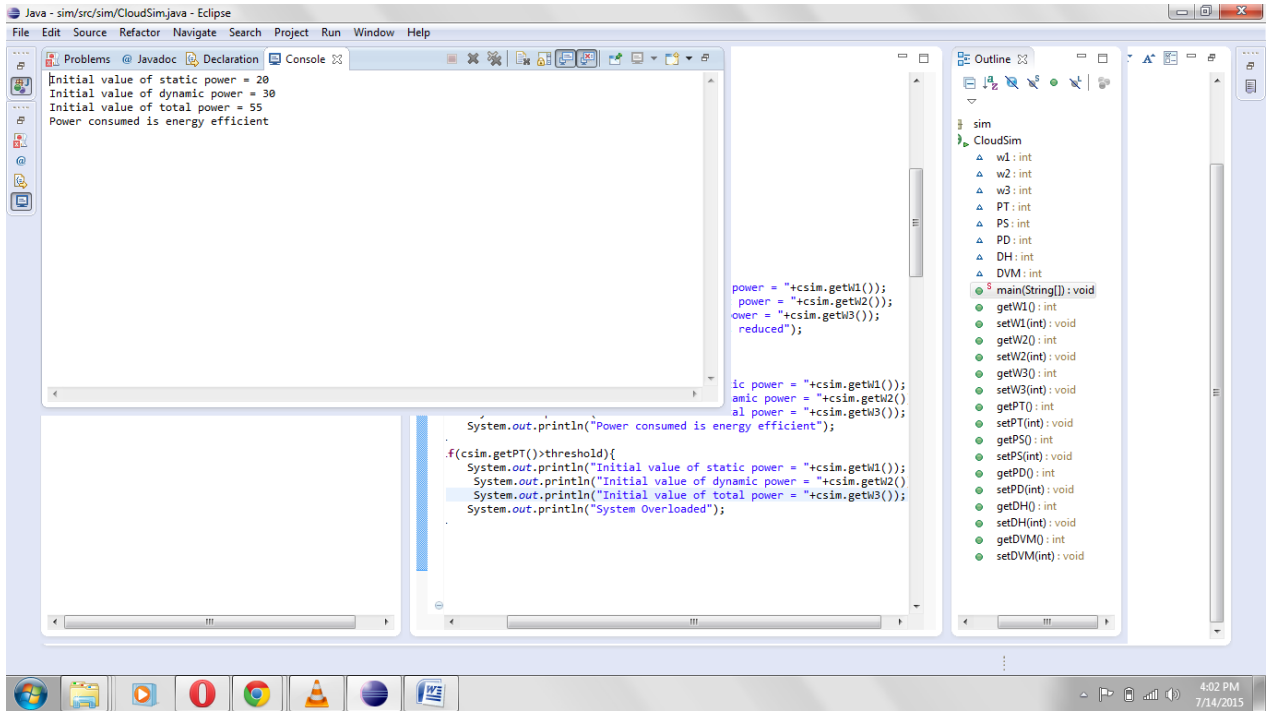


Figure 5.3 Represents the case when power consumed is energy efficient

Figure 5.4 shows the output of the case when after migration of the data, the power consumed has still not reduced below the threshold value. Hence the only solution left in this case is to shut one of the Virtual Machines.

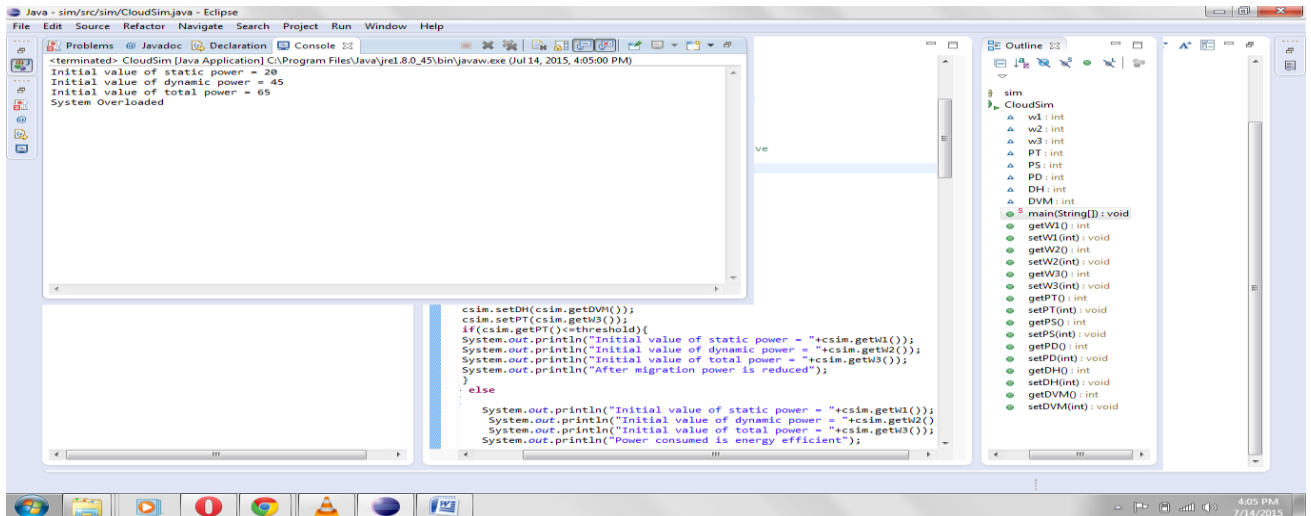


Figure 5.4 Represents the case when the system is overloaded

Figure 5.5 shows the output of the case when initially the total power of the system was more than the threshold value and after migration the total power got reduced.

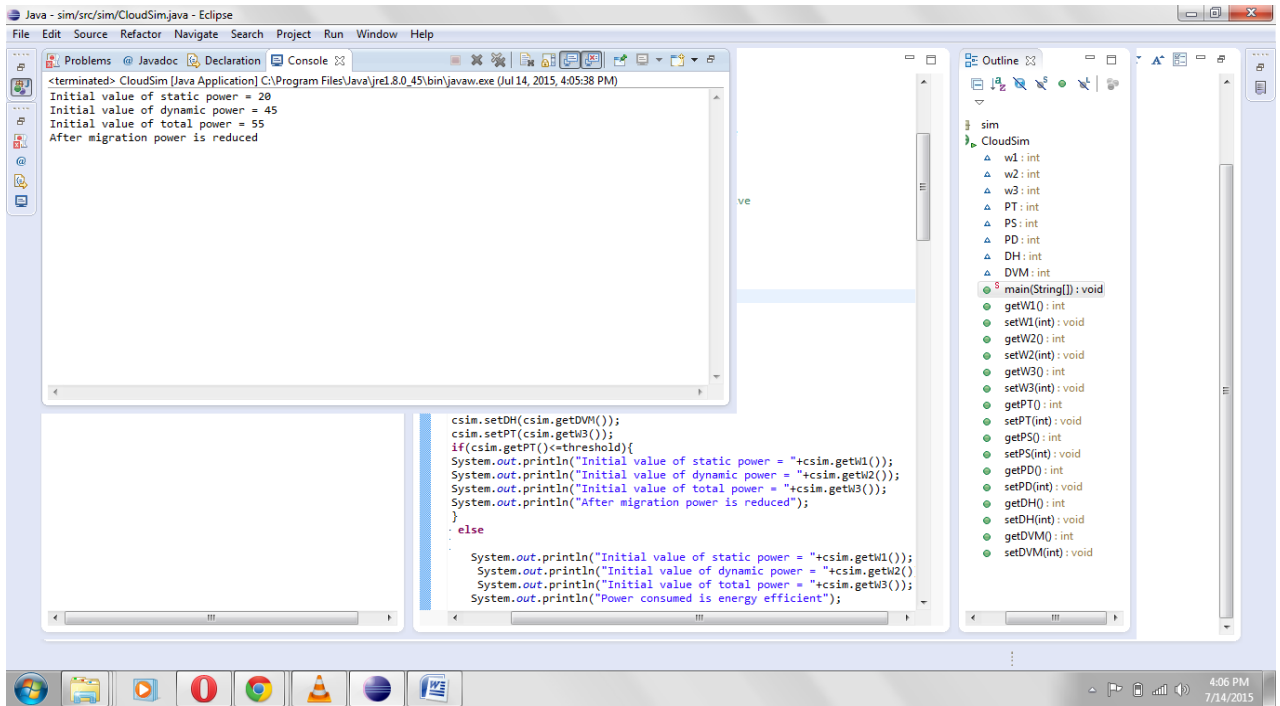


Figure 5.5 Represents the case when after migration of data the power consumed has reduced

### 5.3 Performance Analysis and Conclusion

Analysis is done by making graphs of static energy, dynamic energy and total energy. Figure 5.6 analyze the power consumed by various processors running different tasks and taking different time to execute these tasks. Static Energy will remain constant and Dynamic energy will vary depending on the task.

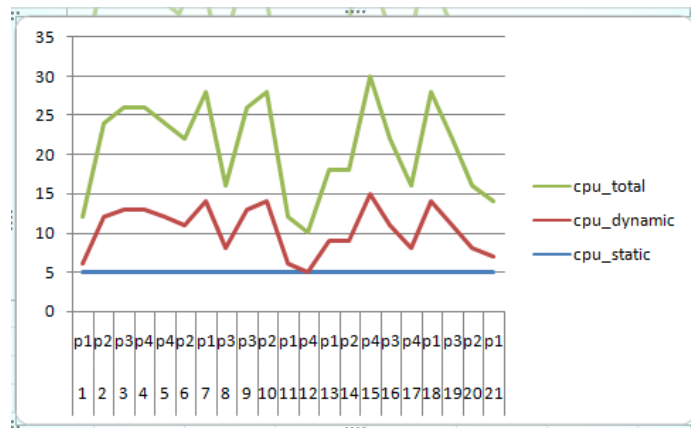


Figure 5.6 Depicting the Static, Dynamic and Total Energy

In Figure 5.7 the black line indicates the threshold level above which the data being used by the respective processors need to be migrated onto the other machine.

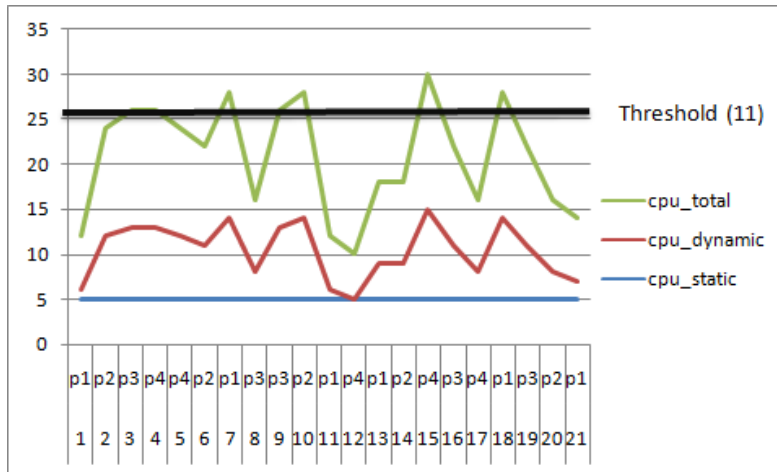


Figure 5.7 shows the threshold power and the tasks to be migrated

Figure 5.8 shows the comparison made between the power consumed by the system referring to the different formulas for calculating power.

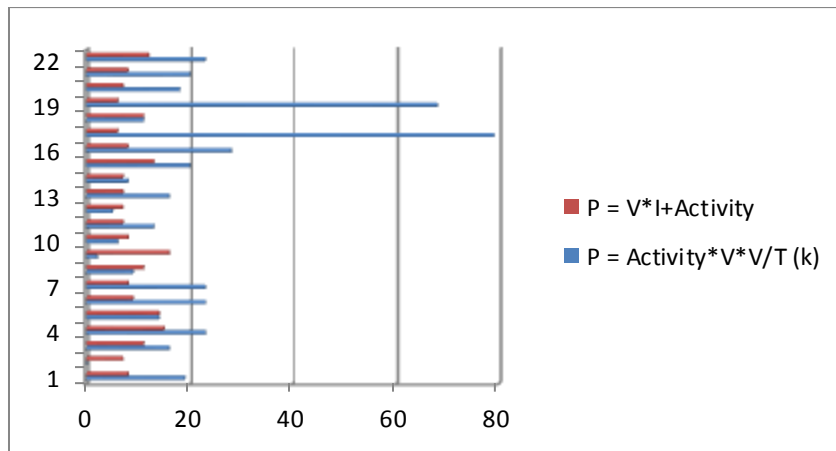


Figure 5.8 Comparison between formula representing power

### 5.4 Conclusion

In this thesis several existing mechanisms for reducing the power consumption in Cloud have been examined. An approach has been proposed for reducing the power consumption. Result of the proposed algorithm has been collected using CloudSim tool.

## Chapter 6

### Conclusion and Future Scope

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This chapter discusses the conclusions of the work presented in this thesis. This chapter ends with a discussion of the future direction which can be taken further.

#### 6.1 Conclusion

This thesis gives an introduction to Cloud computing and also explains the concept of Green Computing. A power reduction algorithm is introduced which reduces the power consumption of the system. This approach has classified the total power into static and dynamic power. By using virtualization and live migration the dynamic power factor of the virtual machine will be transferred to host machine. The virtual machine goes in sleep mode which will result in elimination of its static power and will consume only that much power necessitated for being in sleep mode. Thus, reducing the total power consumed by the system.

#### 6.2 Thesis Contribution

- a) In this thesis existing power reduction techniques have been analyzed and compared according to their features.
- b) A power reduction algorithm has been proposed along with its flowchart and Sequence Diagram.
- c) The proposed algorithm has been coded in CloudSim simulator using Java language and then corresponding outputs have been analyzed.

#### 6.3 Future Scope

This thesis work can be further enhanced in terms of proposing an approach regarding which data to be migrated on which virtual machine by analyzing its power. The migrated data can be divided further into parts and then migrated according to the left over power pool of the processor. The number of times the migration done should be less and can further reduce the power consumption. This factor can too be analyze in future.

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