UNIVERSITI PUTRA MALAYSIA

IMPROVING ENERGY CONSUMPTION IN CLOUD COMPUTING DATACENTERS USING A COMBINATION OF ENERGY-AWARE RESOURCE ALLOCATION AND SCHEDULING MECHANISM

SURA KHALIL ABD

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By

SURA KHALIL ABD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

February 2017

DEDICATION

This work is dedicated to:

My darling Mother and precious Father

For their endless support and love

My dear Sister, Brother, and their Families

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

IMPROVING ENERGY CONSUMPTION IN CLOUD COMPUTING DATACENTERS USING A COMBINATION OF ENERGY- AWARE RESOURCE ALLOCATION AND SCHEDULING MECHANISM

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February 2017

Chairman : Associate Professor Syed Abdul Rahman Al-Haddad B.Syed Mohamed, PhD
Faculty : Engineering

Cloud datacenters consume huge amounts of electrical energy resulting in carbon dioxide emissions and high operating costs. In 2013, energy consumed by global datacenters was estimated to be between 1.1% and 1.5% of the worldwide energy usage and is predicted to grow further. This thesis introduces a mechanism for dynamic virtual machines (VMs) consolidation in cloud datacenters. The aim is improving the utilization of computing resources that can decrease the number of activated physical machines (PMs) to decrease energy consumption. The main target is to design a combination of energy-aware resource allocation and scheduling mechanism to decrease the overall energy consumption, and active PMs, besides maximizing resource utilization and minimizing VM migration.

In this study, to improve the utilization of cloud resources and reduce the energy consumption of datacenters, a combination of energy-aware resource allocation and scheduling mechanism including DNA based Fuzzy Genetic Algorithm (DFGA) is proposed. By designing a scheduling technique, cloud resources can be allocated efficiently to reduce the energy consumption of the cloud datacenter. Nowadays, DNA plays a vital role in many computing applications due to the massive processing parallelism. In addition, using fuzzy theory in genetic algorithm reduces the iteration of producing the population and assigning the suitable resources to the tasks-based and task length in the node capacity. Therefore, using DNA based fuzzy genetic can obtain the best chromosomes in a few iterations to maximize utilization and minimize VM migration. For subsequent, the energy consumption of cloud computing datacenter is reduced.

Energy consumption was analysed in idle and dynamic states of the server, depending on the energy consumed, processes number and size of the data processed, and size of

the data transmitted for each host.The experimental results were analysed in both synthetic and real Google trace log environments. These experiments were conducted with varying workloads and comparatively analysed through three different metrics: overall energy consumption, resource utilization, and VM migration. The experimental results of applying DFGA algorithm to real Google cloud trace logs show that the energy consumption of the proposed work was 2.15 kWh which was more efficient when compared to other works: Energy-aware Rolling Horizon (EARH) (2.55 kWh), Modified Bit Field Decreasing (MBFD) and Minimization of Migration (MM) (2.65 kWh). The percentage of the system's resource utilization was 82%, compared to other works: EARH (72.8%), MBFD and MM (70%). This study's VMM (X1000) was 2, whereas EARH was 3.2 and MM was 5.

It can be concluded that the proposed combination of energy-aware resource allocation and scheduling mechanism can reduce the total energy consumption of the datacenters. The number of activated servers can be minimized by switching off the idle PMs. The resource utilization ratio can be increased and the number of VM migration can be minimized. Future works can apply the proposed mechanism to other cloud platforms.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

MENINGKATKAN PENGGUNAAN TENAGA DI PUSAT PENGUMPULAN DATA AWAN MENGGUNAKAN GABUNGAN TENAGA MELALUI PERUNTUKAN SUMBER DAN MEKANISME PENJADUALAN

Oleh

SURA KHALIL ABD

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Pusat pengumpulan data mengambil sejumlah besar tenaga elektrik menyebabkan kos operasi yang tinggi serta pengeluaran karbon dioksida. Pada tahun 2013, penggunaan tenaga oleh pusat-pusat data di seluruh dunia dianggarkan antara 1.1% dan 1.5% daripada penggunaan elektrik global dan dijangka terus berkembang. Tesis ini membentangkan satu mekanisme untuk penyatuan dinamik mesin maya (VMS) dalam pusat data awan. Tujuannya adalah untuk meningkatkan penggunaan sumber pengkomputeran yang boleh mengurangkan bilangan mesin pengaktifan fizikal (PMS) bagi mengurangkan penggunaan tenaga. Objektif utama adalah untuk mereka bentuk gabungan peruntukan sumber tenaga secara sedar dan mekanisme penjadualan untuk mengurangkan penggunaan keseluruhan tenaga, PMS aktif, dan pelepasan karbon, di samping memaksimumkan penggunaan sumber dan mengurangkan migrasi VM.

Dalam kajian ini, untuk meningkatkan penggunaan sumber pengumpulan data awan dan mengurangkan penggunaan tenaga daripada pusat data, gabungan peruntukan sumber tenaga sedar dan mekanisme penjadualan termasuk berdasarkan Algoritma Genetik Fuzzy DNA (DFGA) dicadangkan. Dengan mereka bentuk teknik penjadualan, sumber pengumpulan data awan boleh diperuntukkan dengan cekap untuk mengurangkan penggunaan tenaga daripada pusat data awan. Pada masa kini, DNA memainkan peranan yang penting dalam aplikasi pengkomputeran banyak kerana keselarian pemprosesan besar-besaran. Di samping itu, dengan menggunakan teori kabur dalam algoritma genetik mengurangkan lelaran menghasilkan kependudukan dan memberikan sumber yang sesuai untuk tugas-tugas yang berasaskan dan tugas panjang dalam kapasiti sesuatu nod. Oleh itu, menggunakan DNA berasaskan fuzzy genetik boleh mendapatkan kromosom yang terbaik dalam lelaran beberapa untuk memaksimumkan penggunaan dan mengurangkan VM migrasi. Untuk berikutnya, pengurangan adalah dalam bentuk penggunaan tenaga.

Penggunaan tenaga dianalisis di tahap yang sia-sia pada dinamik pelayan, bergantung kepada tenaga yang digunakan, memproses bilangan dan saiz data yang diproses, dan saiz data yang dihantar untuk setiap hos. Dari keputusan eksperimen, hasilnya dianalisis dalam kedua-dua kesan Google sintetik dan log sebenar persekitaran. Eksperimen ini telah dijalankan dengan beban kerja yang berbeza-beza dan dianalisis melalui tiga metrik yang berbeza: penggunaan tenaga secara keseluruhan, penggunaan sumber, dan migrasi VM. Hasil keputusan eksperimen menggunakan algoritma DFGA dengan rekod sebenar kesan awan Google menunjukkan bahawa penggunaan tenaga kerja yang dicadangkan adalah 2.15 lebih berkesan jika dibandingkan dengan kerja-kerja lain: EARH (2.55), MBFD dan MM (2.65). Peratusan penggunaan sumber sistem adalah 82%, berbanding dengan kerja-kerja lain: EARH (72.8%), MBFD dan MM (70%). Kajian ini VMM (X1000) adalah 2, sedangkan EARH adalah 3.2 dan MM adalah 5.

Dapat disimpulkan bahawa gabungan cadangan mekanisme tenaga sedar peruntukan sumber dan penjadualan boleh mengurangkan jumlah penggunaan tenaga daripada pusat data. Bilangan pelayan diaktifkan boleh dikurangkan dengan menutup dua PM terbiar. Nisbah penggunaan sumber boleh meningkat dan bilangan migrasi VM dapat dikurangkan. Kerja-kerja masa depan boleh memohon mekanisme yang dicadangkan untuk platform data awan yang lain.

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I certify that a Thesis Examination Committee has met on 7 February 2017 to conduct the final examination of Sura Khalil Abd on her thesis entitled "Improving Energy Consumption in Cloud Computing Datacenters using a Combination of Energy-Aware Resource Allocation and Scheduling Mechanism" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

A	Ampere
AC	*Alternating current*
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CO_2	Carbon Dioxide
CMOS	Complementary Metal Oxide Semiconductor
CPU	Central Processing Unit
CsGO	Crossover Genetic Operator
DC	Direct Current
DCD	Data Carrier Detect
DFGA	DNA based Fuzzy Genetic Algorithm
DRAM	Dynamic Random Access Memory
DPM	Dynamic Power Management
DVFS	Dynamic Voltage and Frequency Scaling
E	Energy
EARH	Rolling-horizon Scheduling Architecture
ELE	Electrical Tools
EPA	Environmental Protection Agency
GA	Genetic Algorithm
GPS	Global Positioning System
HD	Hard Drive
IaaS	Infrastructure as a Service
IBM	International Business Machine
IoT	Internet of Things

IPC	Instruction per Cycle
IQR	Inter quartile Range
IT	Information Technology
kWh	kilowatt-hour
LBACO	Load Balance Ant Colony Optimization
LR	Local Regression
LRR	Robust Local Regression
MAD	Median Absolute Deviation
MAXU	Min-min and Max-min utilization
MBFD	Modified Bit Field Decreasing
MC	Maximum Correlation
MGO	Mutation Genetic Operator
MIPS	Million Instruction per Second
MM	Migration Policy
MMT	Minimum Migration Time
MPC	Memory Access per Cycle
OLB	Opportunistic Load Balancing
OS	Operating System
OSes	Operating Systems
P	Power
PDU	Power Distribution Unit
PMs	Physical Machines
Qe	Queue
QoS	Quality of Service
RASA	Resource-aware Scheduling Algorithm

RC	Random Choice
RR	Round Robin
RU	Resource Utilization
RWSm	Roulette Wheel Selection Method
SaaS	Software as a service
SLAs	Service Level Agreements
SLV	Service Level Agreement
SPM	Static Power Management
T	Time
TL	Task List
UPS	Uninterruptable Power Supply
V	Volt
VDI	Virtual Desktop Infrastructure
VMs	Virtual Machines
VMM	VM Monitor (Mentioned in Chapter 2)
VMM	Virtual Machine Migration (Mentioned in Chapter 3, 4, and 5)
W	Watt
WDM	Wavelength-division Multiplexing
Wh	Watt-hour

CHAPTER 1

INTRODUCTION

1.1 Background

As of recently, applications and data can be maintained and stored in remote servers on the Internet by IT users by utilizing the cloud computing paradigm. Besides storing, any device can be utilized, provided it has Internet service, cloud computing enables the users to access their applications and data in anywhere and at anytime. Improvement and optimization in energy-efficiency, elasticity, flexibility, software and hardware resources utilization, performance isolation, and on-demand service design are all causes that have aided cloud computing to become such a widely preferred technology by many Internet companies such as eBay, Amazon, Yahoo, and Google (Khan, 2016). These companies operate many cloud datacenters worldwide.

Demands for these datacenters have consolidated hundreds and thousands of servers with other forms of infrastructure, such as cooling, storage, and network systems. The commercialization of these developments is currently defined as cloud computing (Pooja, 2011). Cost and quality are the major considerations when scheduling cloud computing network services as datacenters consume a huge amount of energy which results in high cost and carbon emission (Beloglazov et al., 2012). The datacenters are mostly occupied by low-cost and underutilized volume servers for processing data and servicing customers. As shown in Figure 1.1, the datacenters' energy usage has risen around the world from 2005-2010 by 56% (Barroso & Hölzle, 2011). By 2020, it has been predicted that 2% of the world's energy consumption will be consumed by datacenters (Wang et al., 2016). For example, U.S. datacenters in 2006 consumed 1.5% of the total energy, with an increase of 18% per year. This consumption become a serious burden on the energy supply and causes environmental pollution as 0.555kg of CO_2 is generated by consuming one kWh of electricity (Wang et al., 2016). Furthermore, the cost to operate datacenters will exceed hardware purchasing with the gradual depletion and price escalation of traditional energy (Karakoyunlu & Chandy, 2016). Lately, 20,000 servers are monthly appended by Microsoft to their server farms to meet the demands by the users and business. Besides consuming massive amounts of energy, these servers can produce a huge amount of carbon emission (Koomey, 2011). In an average server environment, 30% of the servers operate in idle state. The utilization ratio is low as it is about from 10 to 50% (Maio et al., 2015).

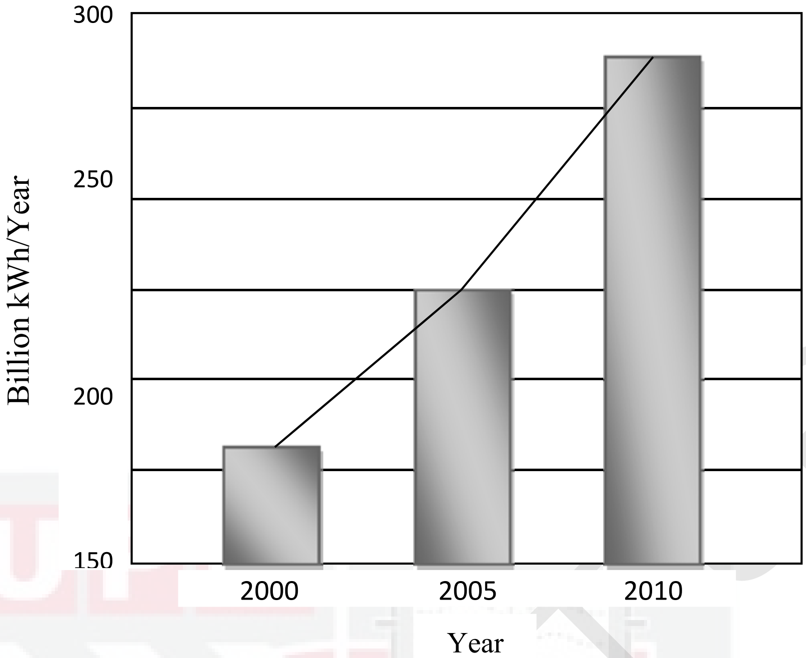

Figure 1.1 : Worldwide Datacenters Consumed Energy from Year 2000 to 2010 (Maio et al., 2015).

The issue of the underutilized server is exacerbated by narrow dynamic power ranges of servers where, even when the servers are fully idle, they still consume up to 70% of the power at their peak (Orgerie et al., 2014). Therefore, from the perspective of consumed energy, keeping the servers underutilized is considered inefficient.

To address this issue and how it can be solved, it is important first to provide a description of the main components that are needed in order to design green cloud environment. Figure 1.2 presents the high-level architecture for supporting energy-efficient service allocation in a green cloud computing environment (Procaccianti et al., 2014). This architecture includes the basic entities: consumers who make the requests for cloud services from anywhere in the world and green service allocator which acts as the interface between consumers and the cloud infrastructure.

To manage the resources in an energy-efficient way, this architecture also demands the interaction of some other components:

a) Green negotiator: Negotiates with consumers to finalize SLAs with identified cost by relying on the schemes of energy saving and the requirements of QoS.
b) Service analyzer: Once the task is arrived, the related service requirements are analyzed taking the advantage of the information extracted from the energy monitor and VM manager.
c) Consumer profiler: Collects particular consumers' characteristics where significant ones can be granted special privileges and priority over others.
d) Pricing: Specifies the charging method of service requests.

e) Energy monitor: Information on VMs' and PMs' energy consumption is gathered and submitted to the VM manager, by assisting in making decision on energy-efficient resource allocation.
f) Service scheduler: Allocates tasks to VMs and specifies resource entitlements for the assigned VMs.
g) VM manager: It is in charge of tracking VMs' availability and their resource usage, creating new VMs, and reallocating them to adapt the placement.
h) Accounting: Observes the actual VMs' resource usage and calculates the consequent costs.

Multiple VMs that run concurrent applications based on different OSs can be dynamically initiated and terminated on a PM, relying on the receiving tasks. By dynamically migrating VMs across PMs, workloads can be consolidated and idle PMs can be switched off in order to save energy. For PMs, the hardware's infrastructure is provided by the underlying physical computing servers to create virtualized resources to meet service requirements.

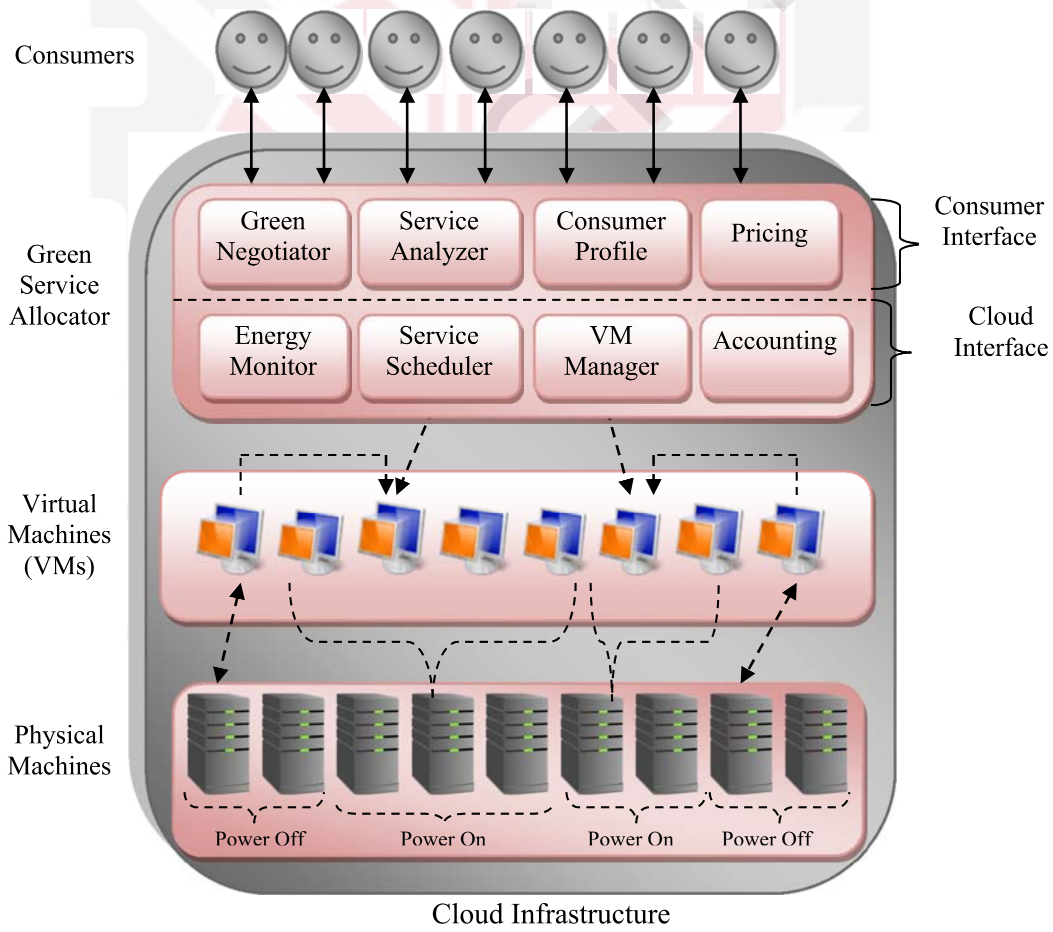

Figure 1.2 : High Level System Architecture (Procaccianti et al., 2014)

Based on the previous architecture, some mechanisms are proposed to provide an energy efficient cloud datacenter. For example, a mechanism that has proven its ability to improve the resource utilization and lower the percentage of consumed energy is dynamic consolidation of VMs, applied via virtualization technology (Choudhary et al., 2016; Madhu & Chandra, 2016). Virtualization is employed to decrease the consumed energy through consolidating several VMs' execution on the same physical host (Corradi et al., 2014). The basic concept in executing the VMs on the same physical servers is to concentrate the workload on a small number of physical servers, hence reducing the active PMs' number. For instance, when there are a couple of PMs, each runs on a VM, yet both do not utilize the maximum computational capacity (Zhang et al., 2014).

This situation can be seen as a waste of computing resources which causes unnecessary power consumption. To get a more efficient utilization, both VMs should be run on a single PM where the second PM can be switched off. As a result, it can be concluded that power saving can be more effective in large-scale datacenters where many physical servers can be managed to save more energy (Zhang et al., 2014). Generally, virtualization and consolidation are effective techniques in maximizing the utilization of underutilized server capacity to reduce the energy consumption of the datacenter and carbon emission (Uddin & Rahman, 2010).

In virtualization, the process of moving a VM from one server to another is called VM migration (Shetty et al., 2016). VM migration allows the running of a VM to migrate from one PM to another without disconnecting the client service, meaning without any notable downtime. In this case, it is called live VM migration (Li & Wu, 2016). Live VM migration is commonly used to balance the work of PMs, provide better sharing of infrastructure, elastic scaling, better fault tolerance, ease of hardware maintenance, and, most importantly, reduce energy consumption when employed by virtualization and consolidation techniques (Kansal & Chana, 2016).

Despite the benefits, live VM migration can lead to serious issues such as traffic congestion and performance degradation (Kang et al., 2016). VM migration should be reduced. Therefore, this thesis focuses on the problem of energy consumption in cloud datacenters by guaranteeing that computing resources are efficiently exploited to serve application workloads, reduce energy consumption and lower the number of VM migrations, with no conflicts with the improved level of energy consumption.

1.2 Problem Statement

In cloud datacenters, the process of resource allocation is considered a challenge as it needs to maintain the power saving of cloud datacenters (Singh & Prakash, 2015; Karakoyunlu & Chandy, 2016). Improving the mechanism of energy-aware resource allocation requires scheduling and managing the requested resources when the hosted applications meet the providers' goals, such as by enhancing resource utilization which, in turn, affects energy efficiency (Hameed et al., 2014; Wang et al., 2016). Resource utilization is an important factor that can become degraded due to a lack of efficient load distribution by having unsuitable scheduling or allocation mechanisms (Wolke et al., 2016). Hence, to improve energy efficiency, the utilization ratio should be improved (Thamarai et al., 2014).

Although virtualization attempts to balance the load dynamically, there is always a chance of the resources becoming over or underutilized. Overloaded PMs can cause performance degradation, whereas poor resource utilization can be caused via underloaded PMs (Patel & Jani, 2015). More heat is generated via overloading PMs which, in turn, increases cooling costs and CO2 emissions, contributing to the greenhouse effect. However, wasted consumed energy can be incurred by underloading PMs (Paul et al., 2016). Therefore, improving the ratio of resource utilization is important in achieving less heat generation, CO2 emission, and energy consumption (Zhou et al., 2016). To improve utilization and save energy, some mechanisms are proposed, such as VM migration (Bala & Chana, 2016).

Migrating VMs to limited PMs and switching off the rest is a common technique to improve the utilization (Maio et al., 2015). Recently, VM migration is widely utilized to adjust the workload dynamically (Sedaghat et al., 2016; Sun et al., 2016), and lower the utilized PMs' number (Ye et al., 2015; Jung & Kim, 2016). Despite the benefits in improving energy efficiency, VM migration can lead to problems. Performance degradation can happen when co-locating VMs or with the shared resources' competition such as the network (Mann, 2015; Kang et al., 2016). Various migration overhead levels can be incurred via migrating VMs with various workloads (Shahzad et al., 2015; Zhang et al., 2016). Security problem can occur when data are migrated in an unencrypted way (Huang et al., 2016).

1.3 Research Objectives

To minimize the issues outcome from frequent VM migrations, the number of VM migrations should be reduced. However, this reduction should not conflict with the need to improve the utilization ratio or affect the energy efficiency of a cloud's datacenters. Thus, the main aim of this study is to reduce energy consumption in the cloud's computing infrastructure and to maximize resource utilization and reduce the number of VM migrations. The research objectives of this study are as follow:

a) To design an energy-aware allocation mechanism that can minimize the overall energy consumption and reduce active PMs.
b) To design a scheduling technique that can assist in maximizing resource utilization and minimizing the number of VM migrations.
c) To evaluate the proposed mechanism in comparison to the other recent energy management mechanisms in terms of energy consumption, resource utilization, and the number of VM migrations.

1.4 Scope of the Study

The current rising demands for the cloud environment require the operation of large-scale datacenters which consume extra energy (Kumar et al., 2016; Hurson & Azad, 2016) . In this thesis, the proposed mechanism focuses on improving energy-efficient datacenters of the cloud computing environment. To provide energy-efficient datacenters, many techniques have been offered such as resource allocation using Dynamic Voltage and Frequency Scaling (DVFS) by Tang et al. (2015a), VM consolidation using VM migration (Vu & Hwang, 2014), efficient server allocation (Farahnakian et al., 2014), and efficient scheduling mechanisms (Beldiceanu et al., 2015). However, recent researches have concentrated on using a combination of allocation and scheduling mechanism to obtain improved results in terms of energy consumption and resource utilization (Fonseca & Queiroz, 2015). Generally, many of the energy-efficient systems are based on VM migration to consolidate VMs or use specific utilization thresholds for a host to switch off the idle hosts and save energy (Beloglazov et al., 2013). However, depending on live VM migration, these mechanisms can lead to performance and traffic congestion issues. In addition, depending on the utilization threshold, these mechanisms limit the system's efficiency based on the suggested static threshold points.

Basically, the focus of this thesis is to propose an energy-efficient datacenter based on allocating user tasks to VMs using the proposed scheduling technique, depending on the node capacity, processing speed, and task length, to be calculated by an application and power control manager. Then, different task conditions are checked, such as the task workload, time consumption, and task time deadline to apply the proposed scheduling technique which can minimize the need for VM migration and avoid the limitation of the threshold mechanism, as explained in chapter 3 later.

Figure 1.3 illustrates the scope of this thesis, starting from the cloud computing system and the implementation environment, which includes platforms, datacenters, and communication networks. In datacenters, there are many related issues such as energy consumption, load balancing, and security. In this thesis, energy consumption is addressed by discussing the most recent energy-saving strategies. Based on the discussion, it is pertinent to combine the energy-aware resource allocation and selected scheduling technique to improve the utilization ratio and minimize VM migration, hence improving energy efficiency. The software tools that were utilized in this thesis are demonstrated in this figure. In addition, to validate this work, CloudSim and real world cloud MapReduce trace logs were employed. Three performance metrics were estimated: total energy consumption, resource utilization, and VM migration. These metrics were compared to some recent energy-saving strategies to demonstrate the improvement by using the proposed mechanism.

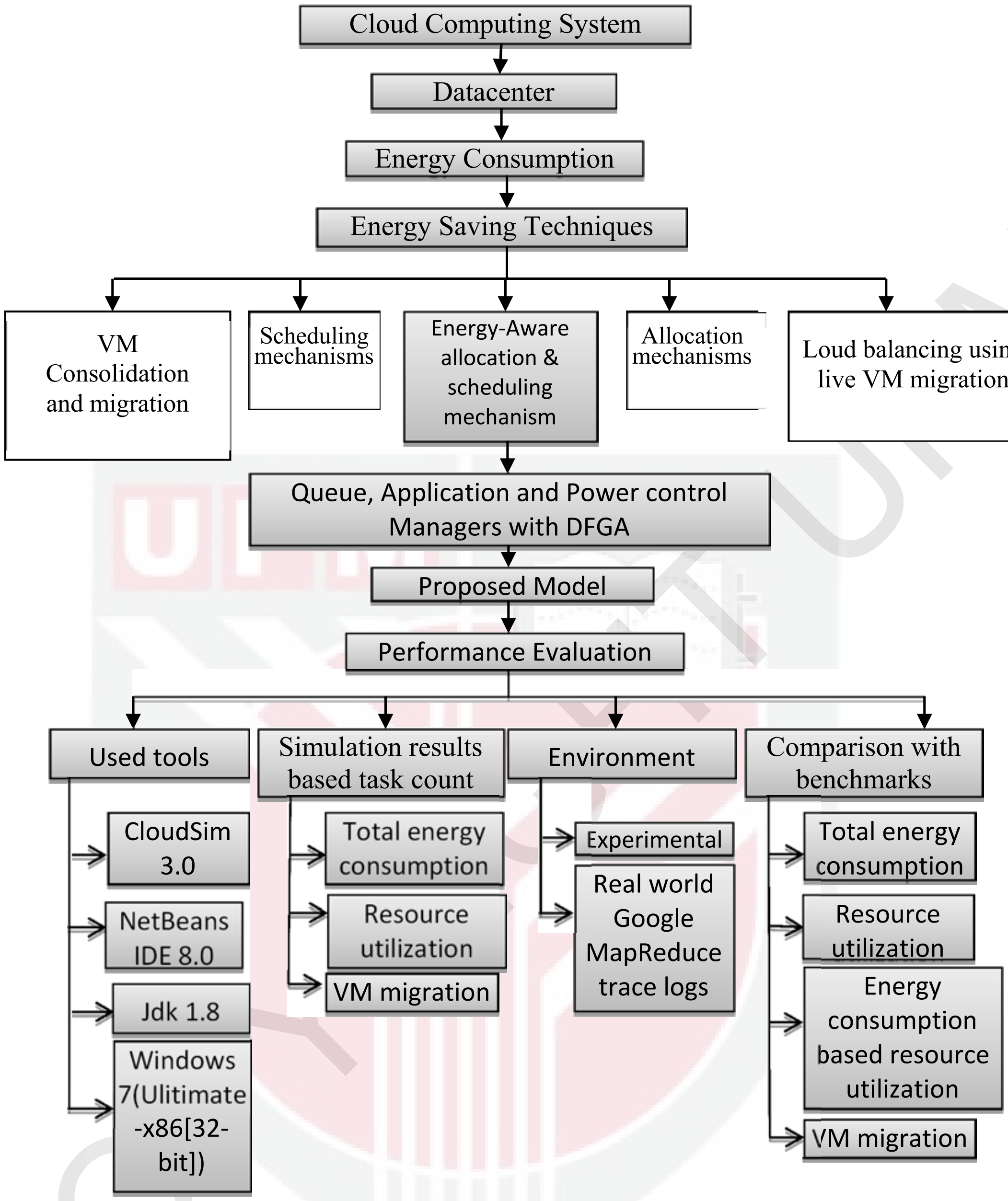

Figure 1.3 : Block Diagram of the Research Scope.

1.5 Thesis Organization

This thesis concentrates on the topic of energy efficient technique for the cloud datacenter. Cost effectiveness can help to maintain a high overall efficiency for the system. This thesis is organized as follow:

Chapter 2 is dedicated to the literature review on the challenges of energy consumption in cloud computing databases, which is the scope of this study. The causes of inefficient energy consumption and the energy sources utilized are elaborated in this chapter. Furthermore, solutions in this field are illustrated and discussed.

Chapter 3 describes the system's model, performance, metrics, and methodology used for designing an energy-efficient resource allocation and scheduling mechanism including DFGA scheduling algorithm. The experimental setup for the evaluation of the proposed mechanism is also introduced in this chapter.

Chapter 4 discusses the experimental results of the proposed technique. A simulation was conducted to show the performance of the exact algorithm and demonstrate its ability to achieve significant energy saving when compared to previous solutions in an experimental environment and real Google MapReduce world trace log environment.

Chapter 5 describes the conclusions of this thesis, the contributions, and suggestions for future works.

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