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Green Cloud - Load Balancing, Load Consolidation using VM Migration

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GREEN CLOUD - DYNAMIC LOAD BALANCING AND LOAD CONSOLIDATION USING VM LIVE MIGRATION

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GREEN CLOUD - DYNAMIC LOAD BALANCING AND LOAD CONSOLIDATION USING VM LIVE MIGRATION

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11/21/17
Dean, Graduate Studies and Research Date

DEDICATION

To my mother, father, sister, and friends.

&

To the faculty of the Computer Science Department at Western Kentucky University.

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LIST OF ABBREVIATIONS

API	Application Program Interface
AWS	Amazon Web Services
CDC	Cloud Data Center
CPU	Central Processing Unit
EC2	Elastic Compute Cloud TM
GAE	Google App Engine TM
IaaS	Infrastructure as a Service
IBM	International Business Machines
ICT	Information and Communications Technology
IP	Internet Protocol
IT	Information Technology
KVM	Kernel-based Virtual Machine
OS	Operating System
PaaS	Platform as a Service
PM	Physical Machine
QEMU	Quick Emulator
RAM	Random Access Memory
SaaS	Software as a Service
SLA	Service Level Agreement
SSH	Secure Shell

TWH	TeraWatt Hour
VM	Virtual Machine
VT	Virtualization Extensions
WAH	Windowns Azure Hypervisor
XEN	Hypervisor

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Recently, cloud computing is a new trend emerging in computer technology with a massive demand from the clients. To meet all requirements, a lot of cloud data centers have been constructed since 2008 when Amazon published their cloud service. The rapidly growing data center leads to the consumption of a tremendous amount of energy even cloud computing has better improved in the performance and energy consumption, but cloud data centers still absorb an immense amount of energy. To raise company's income annually, the cloud providers start considering green cloud concepts which gives an idea about how to optimize CPU's usage while guaranteeing the quality of service. Many cloud providers are paying more attention to both load balancing and load consolidation which are two significant components of a cloud data center.

Load balancing is taken into account as a vital part of managing income demand, improving the cloud system's performance. Live virtual machine migration is a technique to perform the dynamic load balancing algorithm. To optimize the cloud data center, three issues are considered: First, how does the cloud cluster distribute the virtual machine (VM) requests from clients to all physical machine (PM) when each computer has a different capacity. Second, what is the solution to make CPU's usage of all PMs to be nearly equal? Third, how to handle two extreme scenarios: rapidly rising CPU's usage of a PM due to sudden massive workload requiring VM migration immediately and resources expansion

to respond to substantial cloud cluster through VM requests. In this chapter, we provide an approach to work with those issues in the implementation and results. The results indicated that the performance of the cloud cluster was improved significantly.

Load consolidation is the reverse process of load balancing which aims to provide sufficient cloud servers to handle the client requests. Based on the advance of live VM migration, cloud data center can consolidate itself without interrupting the cloud service, and superfluous PMs are turned to save mode to reduce the energy consumption. This chapter provides a solution to approach load consolidation including implementation and simulation of cloud servers.

Chapter 1

INTRODUCTION

Cloud computing is a popular and crucial term in Information Technology (IT). It's a model which combines grid computing and supercomputing. The main idea of cloud computing is a virtualized resource management which can execute any job [Qian, Luo, Du, and Guo, 2009]. Due to benefits of cloud such as high efficiency, reliability, flexibility, the cloud service's demand has proliferated. To satisfy the enormous amount of requirements from clients, cloud providers have to grow their data center rapidly. The data center has become more extensive and complicated, leading to the need for a better solution to utilize cloud resource to maximize performance. Two trends to enhance performance are optimize the software and develop the hardware; however, hardware manufactures paid more attention to improving the hardware's performance. For instance, manufacturers focus on reducing the energy consumption of their product. However, the performance per watt ratio of CDC has consistently been rising every year [Beloglazov, Buyya, Lee, and Zomaya, 2011]. By this trend, the cost of energy consumed by a server during its lifetime will exceed the hardware cost. To guarantee the performance beside lowering the energy consumption becomes a new challenge and the term Green Cloud is considered the most.

Green cloud is a cloud data center architecture which aims to reduce data center power consumption, simultaneously guaranteeing cloud characteristic [Liu et al., 2009]. According to [Garg and Buyya, 2011], several components of cloud which lead to waste en-

ergy are user/cloud software application, network devices, and cloud data center including cloud servers and supporting systems. This study will mainly focus on designing a cloud data center architecture aimed to consume less energy without Service Level Agreements (SLA) violation. Two concepts need to be explored: load balancing and load consolidation.

Based on the SLA, which is the contract between vendors and their customers set up to ensure the Quality of Service (QoS), load balancing is an essential process which redistributes the entire workload among compute nodes of the cloud cluster to optimize resource utilization and improve the response time while avoiding a situation that existing a overloaded server while another is underutilized or idle [Saranya and Maheswari, 2015]. One of primary resource utilization concept is to remove a condition in which some of compute nodes have heavy workload while others are under load or in idle.

On the other side, the economic model of cloud computing is based on the pay-as-you-go model, in which providing services by allowing users to design resources and charge by what is used [Feller et al., 2012]. The challenge for providers is to create an energy efficient method to handle all their services while meeting the SLA. This challenge provides opportunities to investigate into load consolidation. The only way to reduce electricity consumption is consolidation processes which condenses the number of VMs running on physical compute nodes as much as possible and set idle inactive compute nodes. Hence sluggish computers consume less electricity and generate less heat. The energy consumption of the cooling system is reduced therefore power consumption of entire system reduces significantly.

In data centers, the big challenge for a Green Cloud is to automatically make scheduling decision between dynamically load balancing and consolidating VMs among

physical server to meet the workload requirements meanwhile saving energy. To accomplish the green cloud architecture, a system needs to trigger VMs migration and how to select an alternative physical machine to locate VMs. Load balancing plays essential roles in the management process, based on the capacity of each compute node. The system will automatically reconfigure VMs placed in cloud clusters to ensure sharing the workload equally. Load balancing is often deployed in the peak hours when the requirement of VMs rapidly rises. Cloud cluster consumes an enormous amount of electricity during peak hours to satisfy the availability of the system. The other time, when client's requirements are lower, few compute nodes are running underutilized which leads to waste resources. Load consolidation is implemented to save energy. Load consolidation collects the number of VMs, and the capacity of each compute nodes to calculate and distribute VMs to the smallest amount of physical servers then turn remaining servers to power save mode. VM migration is a method to reverse load balancing state to load consolidation state and vice versa.

In this study, we want to introduce our approach to reach the green cloud. In chapter 2, we briefly summarize the basic concepts related to cloud computing, green computing, etc. Chapter 3 introduces the architecture which used to test the performance of our load balancing and load consolidation algorithms. Chapter 4 brings forward the benefit of live VM migration, and explains how it works. Chapter 5 and 6 open our contribution for load balancing and load consolidation algorithm. Chapter 7 notes limitations of our approach and opened suggestions for future work. The remaining chapters are the conclusion, appendix and references.

Chapter 2

BACKGROUND

2.1 Cloud Computing Concept

2.1.1 History

A distributed system is one computing paradigm invented in the early 1970s in which its foundation is focused on networked computers. A distributed system can be described as the combination of server resources in which all components communicate and coordinate their action by passing messages [Shanmugam and Iyengar, 2016]. By having this feature, all resources inside cloud clusters can access other resources for instance hardware, software, network interfaces and data can be stored anywhere. It is controlled by external devices which connect to the system to achieve transparency, fault tolerance and scalability. One important function of a distributed system which increases its lifespan is the capacity of controlling processes allowing implementation of a particular program on different servers. Figure 2.1 is one example of the distributed system.

In the next computing generation of the early 1990s, grid computing was published. The fundamental idea of grid computing is based on the distributed system. It is the collection of resources from multiple locations which are all interconnected to supply immense computational power to solve a common goal [Shanmugam and Iyengar, 2016]. Compared to distributed computing which is suitable only for small bounder applications, grid computing improved on an interactive workload that affects a large number of files. Grid

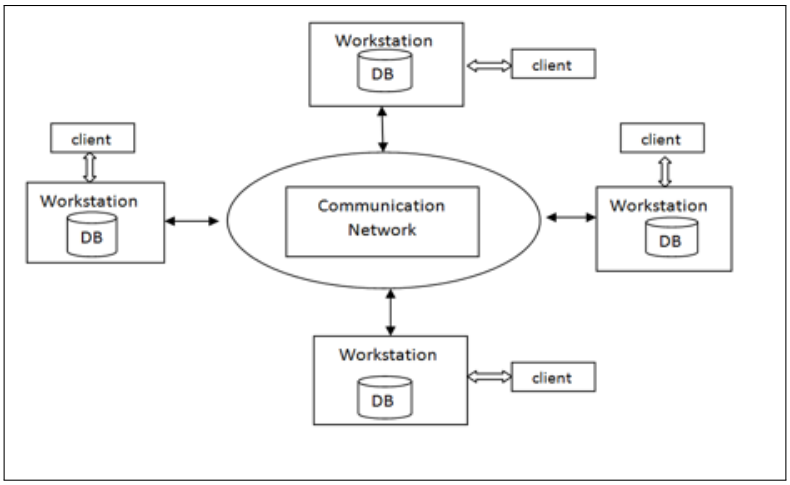


Figure 2.1: Three bands used to classify PMs [Telkikar et al., 2014]

computing controls components which are loosely connected better, and supports functions to network and process tasks from random locations. Figure 2.2 shows a model of grid computing.

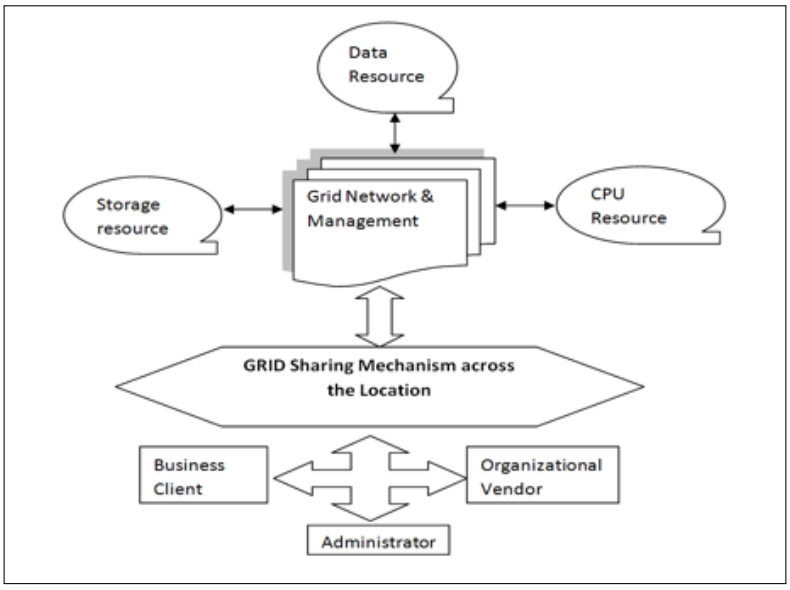


Figure 2.2: Model of grid computing [Shanmugam and Iyengar, 2016]

2.1.2 Cloud Computing Concept

Cloud computing s a model which combines grid computing and super-computing. The main idea of cloud computing is a virtual server which can execute any job. The ori-

gin of the term cloud computing is ambiguous; the word "cloud" in science is commonly related to a humorous object that appears very far from clients. Cloud computing concepts emerged early as 1996 when mentioned in a Compaq internal document [Qian et al., 2009]. With the explosion of the Internet, the increase in customer's demands created tremendous pressure in existing data centers. Internet service providers began changing their orientation to the low-price commodity servers as an underlying hardware platform. According to [Qian et al., 2009], in early 2006, the first cloud project named Elastic Compute Cloud was introduced by Amazon. The fundamental technology of the Amazon cloud is server virtualization. The second version of Amazon's cloud emerged in 2010: Xen - based Elastic Compute CloudTM (EC2) was released with much improvement over the first version. Amazon also released others cloud services such as object storage service (S3) and Amazon Web Services (AWS) which became the pioneer of Infrastructure-as-a-Service (IaaS) provider. One strong competitor of Amazon is Google, starting earlier than Amazon. From 2003 to 2006, researchers from Google published several important research papers which focus on Platform as a Service (PaaS) cloud computing. However, in 2008, Google introduced the first cloud platform called Google App Engine TM (GAE). Due to the fast growth of cloud computing, the giant technology company - Microsoft, joined the race of developing cloud technology. Oct 2008, Microsoft AzureTM was released with Windows Azure Hypervisor (WAH) as cloud infrastructure. Azure also supports object storage and SQL service. Since 2008, cloud computing became a new trend in the computer industry due to two reasons: one reason was because cloud computing could be implemented in many scenarios, and the other was that lots of big companies supported it. According to Hyper Cycle issued from [Cuccureddu, 2011], cloud computing was incredibly fast grow-

ing from 2008 to 2011 compared to other technologies invented in the same period. Figure 2.3 shows the growth of Cloud Computing compared to other technologies developed at the same time.

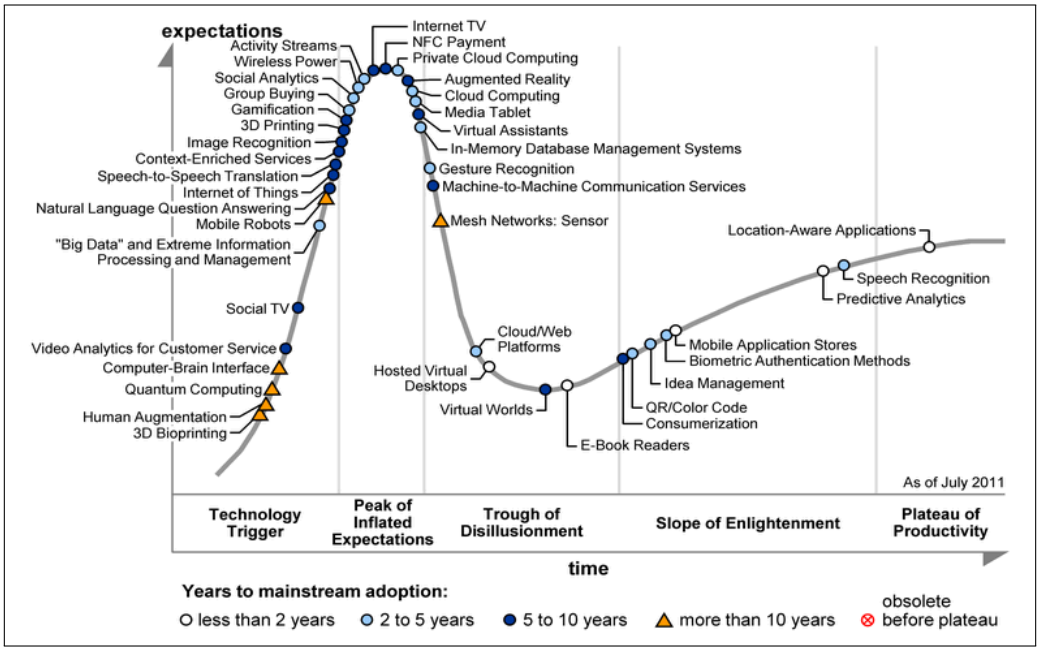


Figure 2.3: Hyper Cycle in 2011 of Gartner Group. [Cuccureddu, 2011]

Cloud computing's basic concept

Following the past, many definations of cloud computing were introduced, one mentioned cloud which was a platform based on the internet to supply resource like services, applications [Saranya and Maheswari, 2015]. Before going deeply for these cloud computing features, we need to understand some basic concepts for instance virtualization, hypervisor.

Virtualization - Concept and Benefit

In computing, virtualization is a generous perception related to the abstraction of resources. According to Wolfgang Kellerer, [Khan, Zugenmaier, Jurca, and Kellerer, 2012] this concept was first used when introducing the idea of time-sharing. At that time, IBM

Watson Research Center implemented a project named the M44/44X Project in which were created virtual machines (44X) to image the real computer (M44). The project was a step toward the implementation of virtual machine monitors which could generate multiple VMs performing different operating systems. Only now, few decades after are we achieving more success in virtualization, more functions, more efficient ways to generate and maintain VMs and PMs. The main achievement of virtualization was the implementation of improving the way to use adequately available physical resources. Moreover, the concept of isolation also implied in virtualization, which was either from the point of easy deployment, a collection of applications, or implements in application isolation or parallels at the same time. Cloud computing also is a kind of virtualization service that using a network of remote virtual servers hosted on the internet to provide shared processing resources and data rather than a local server or a personal computer. All the processes of cloud computing such as collecting and performing resources are managed automatically. Nowadays, cloud computing plays a significant role in a virtualization environment. Cloud computing contributes a great combination of online resources including data storage, network, user application, etc.

Hypervisors

In virtualization, virtual machine monitors, defined as hypervisors, are the low-level programs in the middle of hardware and OS. The hypervisor allows users to run multiple OSs on one PM in real-time. There are two types of hypervisors: type 1 and type 2. Type 1 hypervisor is a thin layer of independence code interacting directly with the hardware of the PM. This hypervisor provides working isolation environments for each virtual machine, high performance, availability, and security. In type 2, the hypervisor is

controlled by the OS. It's more convenient for users to implement and deliver the VMs to any server. However, the security is the most concern issue when this type of hypervisor is implemented.

There are five main hypervisors offered now which control 93% of the cloud computing market [Botero et al., 2013]. Three closed-source are AWS, VMWare and Hyper-V and two opened-sourced Xen and KVM. This study didn't focus on closed-source impervious because of the limited permission on it, so Xen and KVM were the best architectures to research. In this study, I use KVM as a hypervisor for my cloud cluster. Below is a summary KVM's construction trail [Botero et al., 2013] .

KVM is a relatively new open-source project dating back to Red Hat's acquisition of Qumranet in 2008. Its adoption has spiked since it was made part of the main Linux kernel branch starting from version 2.6.20, becoming the primary virtualization package in Ubuntu, Fedora, and other mainstream Linux operating systems. Each guest VM runs as a separate user processes and has a corresponding QEMU device emulation instance running with it. The difference between Xen and KVM is that KVM itself runs as a module inside a host OS, which clarifies KVM as a Type-II (hosted) Hypervisor. Figure 2.4 describes the architecture of KVM.

Cloud Computing Deployment Models

There are four deployment models applied in the cloud environment [Saranya and Maheswari, 2015]:

- Public: The cloud infrastructure is provided in the public, which is opened for renting over the internet.

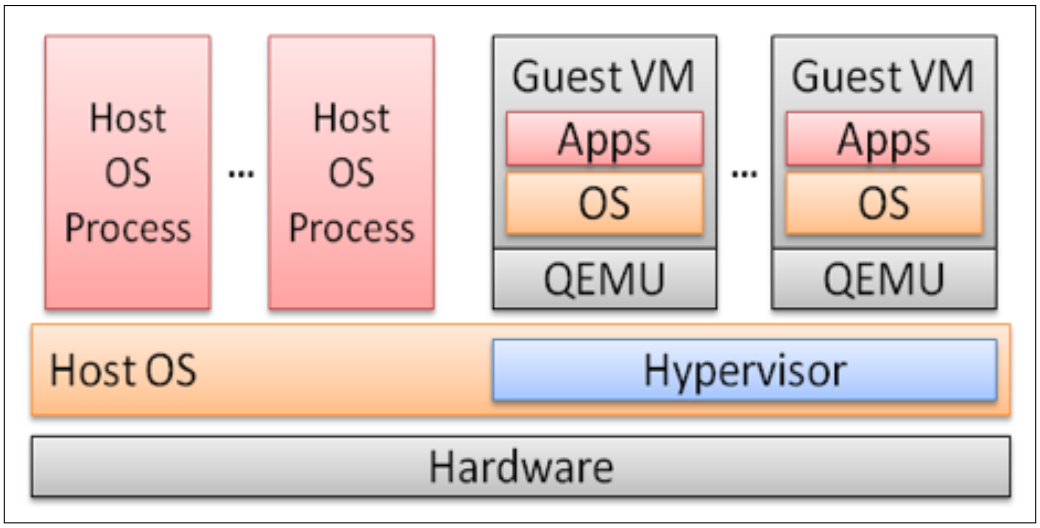


Figure 2.4: KVM Architecture [Botero et al., 2013]

- Private: The cloud infrastructure is deployed for single organization to support interior services and assure the security of organization's resources.
- Community: The cloud infrastructure is shared between several organizations bellowing to a specific community to reduce the cost.
- Hybrid: The cloud infrastructure consists of two or more deployment clouds, the combination between private cloud and public or community cloud.

Cloud Computing - Three Basic Service Models

Although cloud computing has changed over time, it still provides three basic service models: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) based on diverging client demands [Saranya and Maheswari, 2015] [Erl et al., 2013]. Infrastructure as a Service (IaaS): At the lowest layer, this service model represents a virtual self-contained IT environment that can be manipulated via cloud tools. The environment comprises virtual resources acting like raw IT resources for instance virtual servers, virtual networks or specific hardware that guarantees application isolation and

customize runtime environment. The hypervisor stays on top to manage resources. With the IaaS model, the vendor will control virtualization, servers, storage, networking besides, users are allowed to run their operating system, middleware, runtime, data, application. The primary purpose of an IaaS model is to provide the highest level of flexibility and management control over the cloud-based environment for consumers then they can design any servers. Figure 2.5 below introduces a virtual server in IaaS environment.

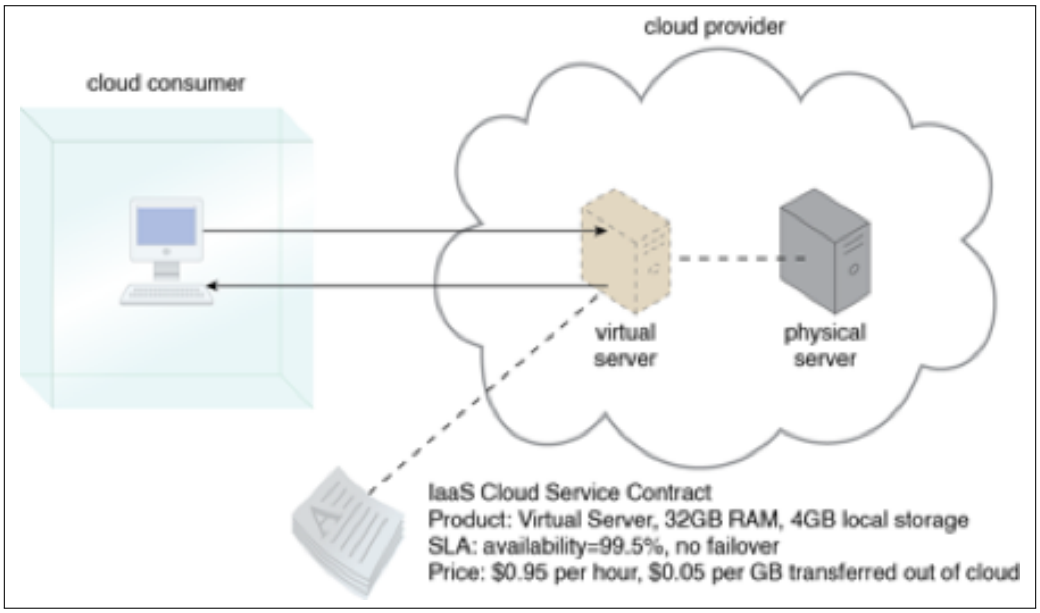


Figure 2.5: IaaS cloud Service [Erl et al., 2013]

Sometimes, to scale cloud service, cloud providers can contact others to extend their services. Type and brand of IT companies which provide IaaS recently include vendors such as Amazon EC2, Windows Azure, Rackspace. Platform as a Service (PaaS): This service model represents the "ready-to-use" environment which eliminates steps needed for an organization to manage the infrastructure hardware and OS. In general, PaaS supports customer only on middleware which allows users to develop and implement on cloud infrastructures. By working with this model, clients have reduced the administrative burden

of developing and maintaining IT resources. Figure 2.6 below is example model of PaaS cloud service.

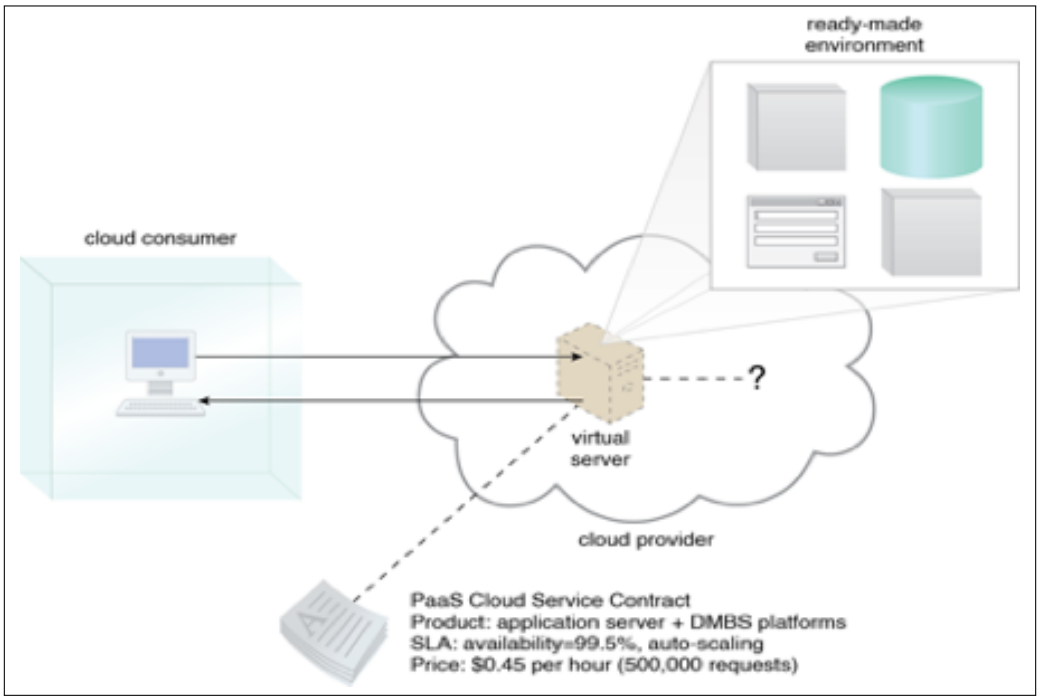


Figure 2.6: PaaS cloud Service [Erl et al., 2013]

Three characteristics which identify PaaS start with run-time frameworks. One provides a coding environment for end-user. Another is abstraction which focuses on developing and manage cloud application on Cloud rather than focusing on raw virtual resources. Finally, cloud service with APIs helps the delivery processes become quick. There are some PaaS services such as AWS Elastic Beanstalk, Windows Azure, Google App Engine.

Software as a Service (SaaS): On the top layer of cloud services, SaaS provides a conveyance software model where an application is brought online and accessed via web browser. In this model, customers don't need to consider the systems behind their software, and cloud providers guarantee all infrastructure to assure stabilizing. All end-users requirements are high-speed performance. Figure 2.7 is an example of SaaS cloud service.

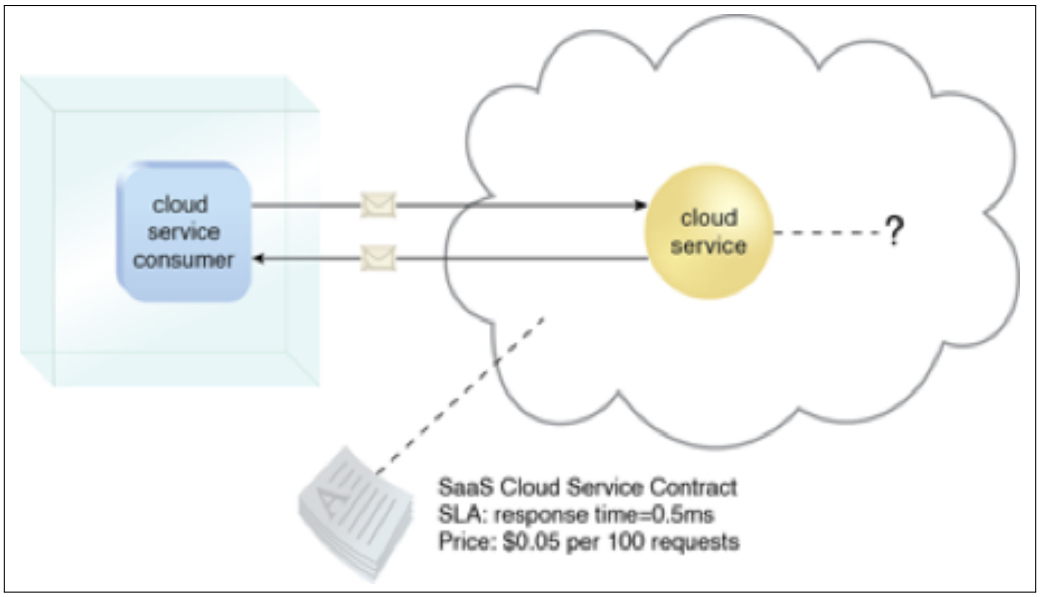


Figure 2.7: SaaS cloud Service [Erl et al., 2013]

2.1.3 Cloud Computing Advantage and Disadvantage

Cloud computing advantage: [Korri, 2009]

Initial cost saving: One of the biggest challenge for companies or individuals when launching a new product or service is initial cost [Korri, 2009]. Cost saving is classified into two sides. One is the investment in the computer system, which includes hardware cost and installation cost. Obviously, the cost of equipment rented from cloud computing provider is much cheaper than the cost of investment in a new computer architecture. With cloud technology, a huge investment in computer architecture is unnecessary. The other side is cost upkeep used to maintain services. Using service from the cloud computing service provider will reduce the cost of hiring IT personnel to support service. Furthermore, the cost can be reduced based on the demand of companies or individuals because the rented fee relies on the usage.

Flexibility: Cloud computing is more scalable than previous generations of com-

puting. According to usage, cloud computing platform can extend their capacity, which is impossible to achieve the equal benefits of in other generations of computing without massive investment in infrastructure. In addition to scale up, users can scale down their service which means a massive infrastructure might be cut off its capacity when a user does not need a vast system behind their service.

Comfortable: When the responsibility of system infrastructures shift from users to cloud service providers, this in turn reduces more burdens of users. They have no longer have to worry about some issues raising during launching their service.

Available: With cloud computing technology, every member of organizations can access their services in anywhere. Reasonable initial cost and deployment becomes easier due to increase new business.

Cloud Computing Disadvantage[Korri, 2009]

Cost model: The model to calculate the usage's price including customer's usage hour, data transfer and amount of storage is complicated.

There is no standard for all cloud providers so the process of moving data from one cloud provider to another could be messed up. The customer should consider which cloud provider is most suitable for their project.

2.1.4 Cloud Characteristics

Virtualization: All resources of the cloud are virtualized so it can achieve the various types of software platforms or operating systems on one physical machine.

Service-oriented: This architecture model provides a system where all its components are connected via the network and everything is represented like service.

Elastic: The cloud architecture allows cloud application to be dynamic provisioned

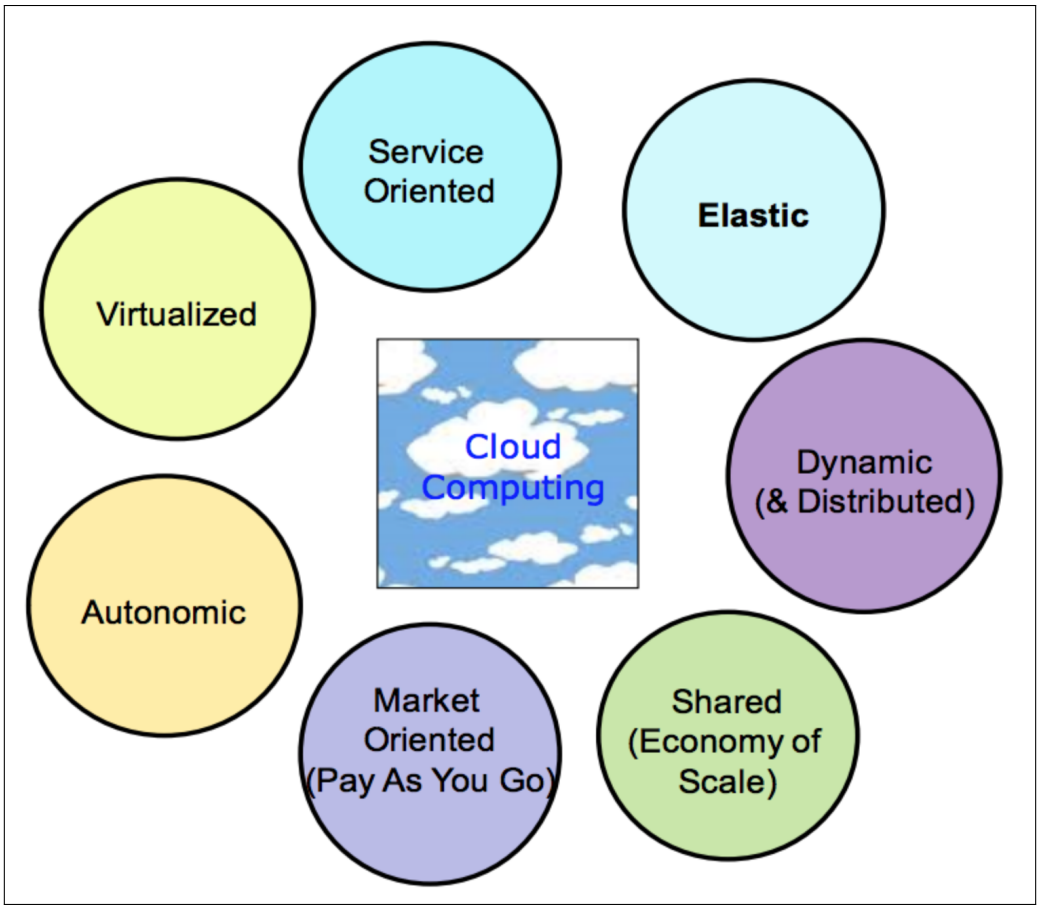


Figure 2.8: Cloud Characteristics

such that the capacity of resources can be automatically increased or decreased at running time depending on user QoS requirements.

Dynamic and Distributed: Although all resources of cloud architectures are represented by virtualization technology, however, high-performance services can still be supported for the user. Based on retirement, the user can be allowed to manipulate the virtual system as their system, for example deciding which operating systems are installed or modifying network configuration for all connections between components.

Shared (Economic of Scale): A cloud architecture based on "multi-tenant" model, all PM are shared, and users neither have authority to directly connect to the physical devices nor recognize the location of the PM which is being shared. Depending on requests

from users, load balancing or load consolidation algorithms are implemented to indicate which physical device will trigger a VM to process the request.

Market-oriented (Pay-as-you-go): Price for using the cloud is calculated based on pay-per-use (pay-as-you-go) model. The price is the diversified form of the quality of service.

Autonomic: to guarantee delivery of dependable service to the customer, the cloud services provide autonomic behaviors which auto-manipulates itself to prevent failure or unanticipated cases.

2.1.5 Cloud Computing Components and Energy Usage Model: A Typical Example

Through a typical Cloud usage scenario [Garg and Buyya, 2011] , figure 2.9 describes a classic components of cloud computing services such as SaaS, PaaS or IaaS. In this section, I will make analysis energy usage of a storage system which allows end-users access and store their data on the internet based on cloud computing and energy usage model.

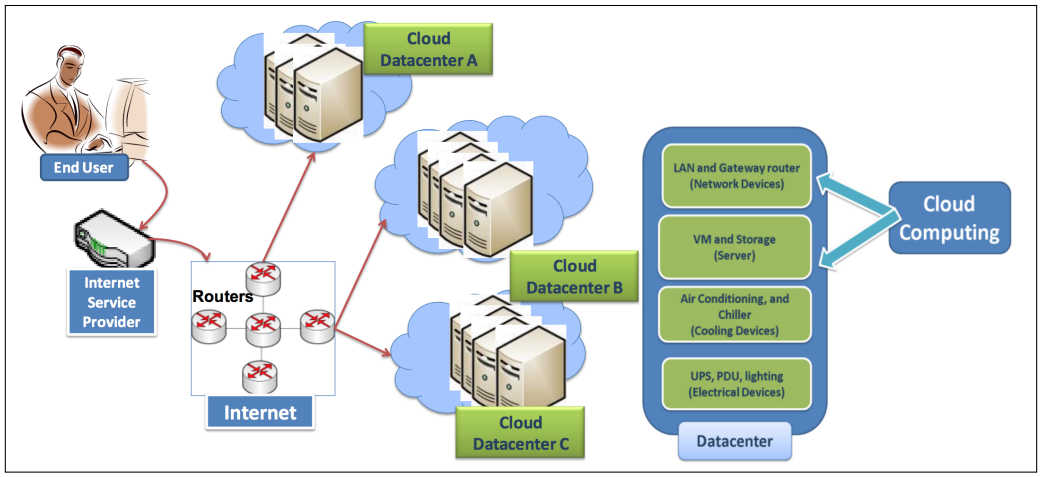


Figure 2.9: Cloud Components [Garg and Buyya, 2011]

To activate cloud service, end users need to connect to the internet via their devices

and internet service provider. User's data will be transfer to Gateway router within a Cloud data center which will find the appropriate cloud data center to process the user requests. Interior cloud data center, data goes through a local network to one virtual machine which will process user data to connect to storage servers to response data back to end user. To guarantee the quality of cloud service, some PMs are turned on to satisfy worst cases lead to huge amount of energy consumption. Further, within cloud data center, there are many devices which stabilize cloud system such as cooling, electrical device or consume power. Besides, to assurance user data from losing, all cloud data centers have to design backup servers located in a different location for recovering. All of those components of cloud data center cause to incredible increment energy usage and associated carbon emissions.

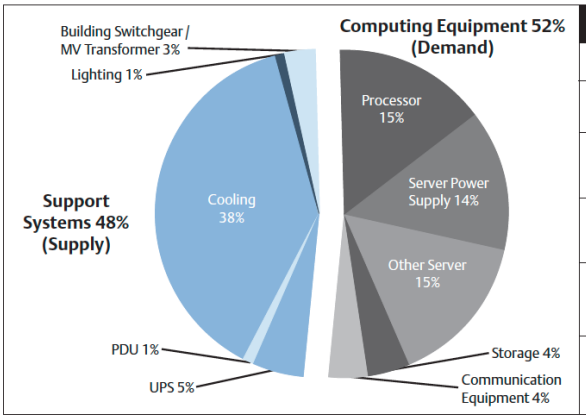
Depending on cloud components some reasons may lead to waste energy:

- User/Cloud Software application: The way software application designed and implemented can be one of the factors that cause to increment of energy usage. If these software desire high performance in an extended period, the consequence of its execution cause to high energy usage. Application inefficiencies as an example, substandard algorithms of using shared resource lead to inappropriate resources usage and, therefore, higher energy requirements. Additional, because of provision qualification of cloud service, cloud provider always is designed to supply user demand in the worst case, this means resources always provide more than the actual requirement. Consequently, user software program in another way can contribute remarkable energy usage. However, most of the development applications are not estimate its power capacity while designing.

- Cloud Software Stack for SaaS, PaaS, IaaS level: Cloud computing in another way defined as a stack, which delivers a set of services built on top of the virtual machine. When designing cloud service, providers have to guarantee Service Level Agreements (SLA) which is a commitment to their customer on the qualification of duty. Besides providing extra provision resources, cloud providers have to maintain their storage, supply backup the storage to avoid failure, assure fast recover and reduce response times. Therefore, it is necessary to discover the relationship between energy consumption and SLA.

- Network devices: In cloud computing, when all resources are accessed through the internet, therefore, both applications and user data desire much more communication bandwidth between user's computer to cloud data center. According to the energy consumption estimation of ICT [G. and Edler, 2015], electricity usage of wired network and WIFI network will continue expanding since it had in the past, until 2030, in the worst case, energy usage of wires network and WIFI network might reach 7912 and 4529 (TWH). So network system is still involving in energy usage of the whole cloud system. In some cases, transfer the significant data by post-office might be cheaper and reduces more carbon emissions rather than using the internet. Because of before data of end-user reaching data center, it has to pass many network devices, and all data is aggregated in Ethernet switch devices then moves to many routers on the internet until it reaches its end point. Each of these network devices consumes a certain amount of energy. Furthermore, [Garg and Buyya, 2011] total usage consumption might be higher than expected to a great communication case. Therefore, with the

expanding of cloud computing service, the energy efficiency of network devices such as switch and router play meaningful momentous roles in cloud services since those devices need to provide an immense capacity for bandwidth and speed. Additional, most of the network devices are wasting energy, the total power consumption is the same during the peak time and idle because they are designed to handle the worst case. There are some solutions to reduce energy usage such as turning off unused network devices when usage is low and waking up in contrast.



Category	Power Draw*
Computing	588 kW
Lighting	10 kW
UPS and distribution losses	72 kW
Cooling power draw for computing and UPS losses	429 kW
Building switchgear/MV transformer/other losses	28 kW
TOTAL	1,127 kW

Figure 2.10: Energy Usage Model of a CDC [Emerson Network Power, 2009]

Figure 2.10 estimates the energy usage of a typical data center. Since the cooling system contributes 35% of overall energy usage, most data center have to implement the best design to control temperature. Computational fluid dynamics (CFD) which bases evaluation of airflow to decide the optimize organization of server rack [Emerson Network Power, 2009].

2.2 Green Cloud Computing

2.2.1 Green Computing

Green Computing (also called green information technology or the Information and Communications Technology (ICT) sustainability) can be described as a study of designing, deploying computer resources such as servers and associated subsystem such as monitors, network devices to less impact on the environment [Raza et al., 2012]. The primary goal of green computing is to cut down or minimize materials which are wasting energy. The other is to endeavor to accomplish economic feasibility and improved system performance.

2.2.2 Some Solutions to Reach Green Computing

Sometimes, solutions to the critical issues started from simple principles. Best work habits of computer administrators and users can help to minimize the impact of computers on the global environment. Here are some patterns that can be taken [Agarwal and Nath, 2011].

- Virtualization: Concerning virtualization, many studies which indicate that with virtualization, the data center can offer significant energy and cost saving [Alzamil, Djemame, Armstrong, and Kavanagh, 2015].
- Processor consumes 15% energy of total based on the analysis above. So, using more-efficient processors is critical energy saving factor.
- Setting the power options of a computer to switch to sleep mode when it's idle.
- Tasks divide.

- Use computer parts which performance efficiency energy such as: using the flat monitor than CRT, avoid screen saver.

The advantages of green computing such as reduces overall energy consumption lead to decrease electricity costs, optimize performance, recycle end-of-life equipment, etc. with the rapid growth of cloud computing, increasing data centers which include cooling systems, equipment power density cause the new trend in cloud computing industry: the green cloud.

2.2.3 Green Cloud

Cloud computing, next generation of computing era, a platform that based on the internet to supply resources like services and applications, has more influence on IT industry. Due to benefits of cloud mentioned above, cloud service's demand has snowballed. To satisfy an enormous requirement from clients, cloud providers have to grow their data center. The data center has become bigger and more complicated. Therefore green cloud model has become the most current concern. Although manufactures paid more attention to improving the hardware's performance such as reducing the energy's consumption of their product, however, the performance per watt ratio has consistently been rising every year [Beloglazov et al., 2011]. By this trend, the cost of energy consumed by a server during its lifetime will exceed the hardware cost. The problem is even worse for the large system such as cluster or data center.

Green cloud is an internet data center architecture which aims to reduce data center power consumption, while at the same time guarantees cloud characteristic [Liu et al., 2009]. To achieve green computing goals, based on factors which lead to waste energy

mentioned in the chapter above, the process to reach green cloud is classified into three main majors: user applications, network systems, data centers. This study will mainly focus on designing data center which contributed the most energy consumption with virtualization solutions to achieve green cloud.

In the data center, the big challenge for a Green Cloud is to automatically make scheduling decisions between dynamically load balancing and consolidating VMs among physical server to meet the workload requirements meanwhile saving energy. To accomplish the green cloud architecture, several keys are related including when a system needs to trigger VMs migration and how to select an alternative physical machine to locate VMs. Those two concepts are applied in load balancing and load consolidation algorithms, which are two powerful strategies to achieve Green Cloud. Load balancing plays essential roles in the management processes, based on the capacity of each compute node, the system will automatically reconfigure VMs stored in the cloud cluster to ensure sharing the workload equally. There are no overloaded compute nodes while the others are idle or underutilized. Load balancing is often deployed in the peak hours when the VMs requests rapidly increases. Cloud cluster consumes an enormous amount of electricity during peak hours to satisfy the requirement of the system. The other time, when client's request are lower, few compute nodes are running underutilized leading to wasted resources. Load consolidation is one of a powerful solution to save energy. Load consolidation collects the number of VMs, and the capacity of each compute nodes to calculate and distribute VMs to the smallest number of physical servers. Then, turns the remaining servers to power save mode. VM migration is a method to reverse load balancing state to load consolidation state and vice versa.

2.2.4 Feature of Clouds Enabling Green Cloud

According to [Accenture Microsoft Report, 2010], there are some features of cloud which can turn to the green cloud.

Dynamic Provisioning: In enterprise computing, the data centers are designed to handle the worst case. Therefore, technology companies have to invest in more equipment than needed. There are two main reasons for such provisioning: It is too hard to predict the usage in the future, most of the companies don't want to upgrade their system monthly or annually. They want their infrastructure can afford the market around five years. Additionally, the new server has to guarantee the level of quality to end user all the times. Website servers are an excellent example of energy efficient. Website host have to provide the high performance in both worst case and idle. This issue becomes simple with cloud service, when a cloud provider can extend their service by making a contract with the web hosts, among others to assure the quality. Thus, data centers only need to maintain current demand without considering over provisioning.

Multi-tenancy: One benefit of cloud services which improve adequate using resources of enterprise servers. Hardware today has much more power than before, because device manufactures have continuously upgraded their products. With virtualization, all resources can both be shared between server tenancy and isolated data leads to a decrease in energy consumption.

Server Utilization: In general, traditional servers typically don't use more than 90% of their capacity. With virtualization, data in each computer node can quickly move to other nodes based on VM migration technology. Thus, all unused compute nodes can be turned

off or switch to low power mode to conserve energy. Those dynamic processes improve the utilization levels up to 70%.

Data center efficiency: As discussed before, the data center is a major factor which impacts energy usage of whole cloud system directly. By cutting down underutilized computer nodes, support system, consisting of network systems, cooling systems, which contribute half of the total energy usage of the data center,, also is cut down too. Additionally, virtualization allows moving data between two data centers which provides high speed for end users by moving their data to the closest data center.

2.2.5 VM Migration

Virtualization recently has become a new trend in computing, due to their structure where all hardware resources are shared over a network to optimize resource utilization. VM migration process, technique, which migrates a VM between hypervisors or physical hosts with purposes such as improving the system performance. There are two kinds of communication mode: live and non-live migration. Live migration allows migrating a running VM from one physical host to another without disrupting service. It means that users will not recognize the movement of their VM between physical host while using the system. This approach helps to improve the continuity and availability of the service. Non-live migration, in contrast, does not support this feature. To migrate, VM should be turned off, then resumed after completing the migration processes.

From [Ahmad et al., 2015]. summarizes in details the applications of VM migration discussed below:

- Power management: For server consolidation, by VM migration, the head node which

controls the whole cloud cluster migrates all VMs into a certain number of physical hosts without reducing performance or existing any overload physical hosts. The remaining physical hosts are turned off to reduce in a significant amount energy consumption.

- Resource sharing: The issues when sharing limited system resource can vary the system performance. It can be solved by VM migration when migrating a "*hungry*" VM to a resource-rich server.
- Fault tolerance: The fault-tolerant system prior interrupts system to handle the failure happening. VM will be migrated back to the original physical host if the destination host failures for some reasons.
- System maintenance: To support the system performance, maintenance processes are frequently implemented during the server time life. All VMs are migrated from the hosts which are under maintenance schedule to the other.
- Load balancing: This application helps the cloud system to avoid failure of a single host cause of heavy workload when existing a light workload host. VMs from the heavy workload physical host migrated to another which is a light workload.
- Mobile computing: Today, people do not prefer to work on their desktop or laptop only. Rather, due to the proliferating of smartphone or tablet, people want to work on these devices which are more flexible when moving. Migration application helps to migrate the workload from operating system of a smartphone to a desktop server or vice verse.

A taxonomy of VM migration schemes

This section highlights and discusses how we classify the current VM migration schemes. Due to [Ahmad et al., 2015], VM migration pattern divided into seven categorizes migration pattern, objective function, network link, hypervisor type, execution resources constraints, migration granularity, network management.

VM migration pattern mainly focuses on the method which uses to migrate VM between two servers. A cloud data center recently implemented two methods which are live VM migration and non-live VM migration. As discussed above, live migration is a process in which migrating a running VM between two hosts without any interruption. In contrast, non-live VM migration requires to shutdown VM before migrating processes. Additionally, live VM migration has three categories which are pre-copy VM migration, post-copy VM migration, and hybrid methods. Pre-copy VM migration mode transfers entire memory to the destination host to low the dirties pages before pausing VM for migration. The method tried to minimize downtime during VM migration process due to rising the network traffic. On the other hand, post-copy VM migration has a better solution to reduce data transfer via the network and optimize the total movement time, but the downtime is much higher than pre-copy VM migration. The hybrid method is the combination of both schemes above.

Objective functions which are using to evaluate migration algorithms including:

- Minimizing downtime which is the period of the time when a VM is down for migrating and the time when the destination host can resume that VM. All VM migration algorithms aim to optimize downtime to guarantee the performance.
- Minimizing the migration duration which is the time when VM starts to migrate until completing the entire VM migration processes.

- Reducing the length of application QoS degradation.
- Optimizing the bandwidth: Although migration is the useful feature, however, it's still an expensive process which mainly based on network bandwidth.
- Network protocol: The metric which specifies the type of network protocol chose to migrate VM. LAN is still a better option to migrate VM in data center due to the stabilizing of bandwidth and connection. WAN attribute, in contrast, has limited bandwidth.
- Hypervisor type: There are so many companies developing their type of hypervisor which outputs with a different feature of migration such as XEN, KVM, VMWare, etc.

Under execution resource constraints metric, VM migration delivers into two forms: shared and dedicated. Under migration granularity metric, VM migrations grouped into single migration processes or multiple migration processes happened at one time. The other metric is network management which classifies VM migration following ARP (address resolution protocol), virtual private network (VPN), mobile IP, IP tunneling, and dynamic-DNS.

When do the cloud clusters need load balancing process?

Load balancing in cloud computing supports a robust solution to setup condition of system's structure. Two primary goals of load balancing are resource provisioning and scheduling in the distributed environment [Raza et al., 2012]. VM migration is one excellent method to deploy load balancing. Figure 2.11 is an example of load balancing using VM migration. Depending on the requirement and information collecting from physical

machines by VM managers, data center controller depend on load balancing algorithms to distribute VMs into the physical machines to satisfy resource provisioning. The other goal is scheduling in the situation when some physical machines are working exceed the standard of SLA so VM managers need to redistribute VMs in the cloud cluster. VM migration is an instrumental method to handle it.

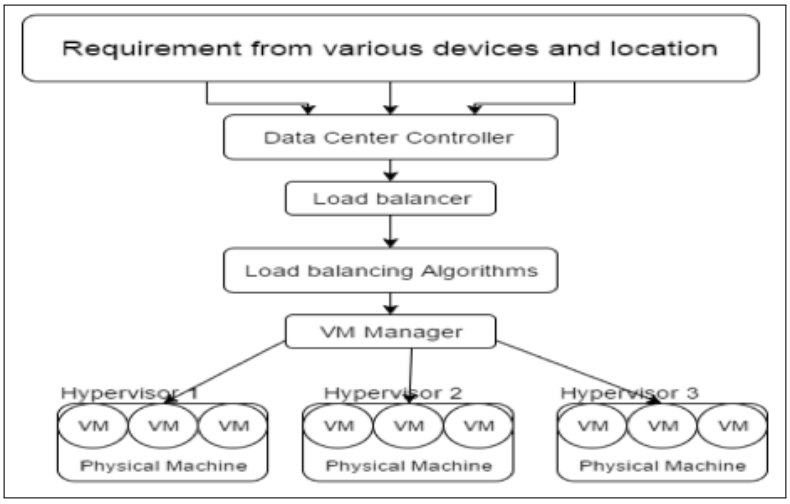


Figure 2.11: VM Migration in Load Balancing [Raza et al., 2012]

For example, three servers have the same infrastructure, for some reasons four VMs are running inside server one but server two only runs two VMs, VM manager will move one VM from server one to server two to balance system. When user's demand becomes lower, there are too many servers are in idle or worked under their power, it is the time to perform load consolidation.

When do the cloud clusters perform load consolidation process?

Usually, cloud data center is developed to provide the client demand to assure absolute service reliability and availability. However, according to the result of the procession of measuring the efficiency of data centers [Uddin, Shah, Alsaqour, and Memon, 2014], on average, about 30% of cloud clusters stay in the idle majority of the time, and it often

is used 10-15% their capacity. In this situation, consolidation is one powerfully strategy, and VM migration is the key solution. Figure 2.12 shows the essential VM migration process on distributed Cloud Data Center (CDC) [Ahmad et al., 2015]. Assume that most of the servers are working under their capacities. At this circumstance, the global manager needs to reconfigure the cloud cluster. All VMs including requesting VMs from dispatcher and VMs are running in underutilized servers are migrated from underutilized servers to resource-rich servers to optimize the set of running servers to reduce electricity consumption.

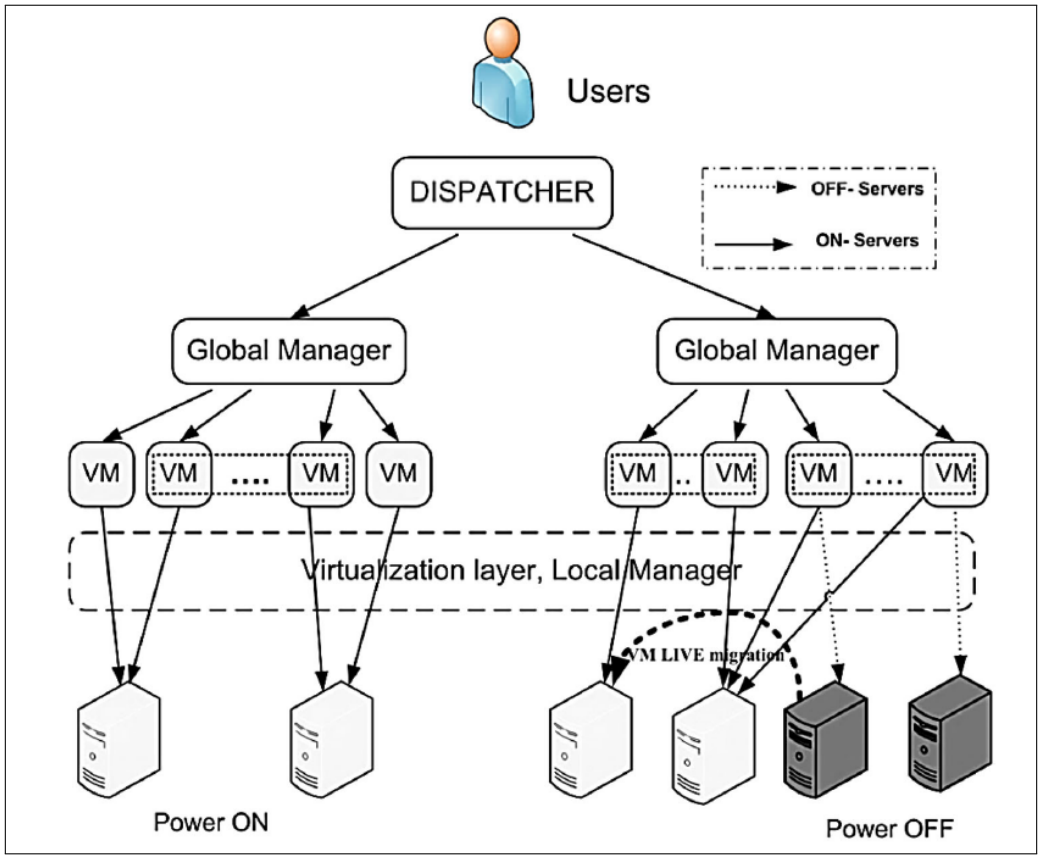


Figure 2.12: VM Migration in Load Consolidation on CDC [Ahmad et al., 2015]

The principal method to migrate a VM from a source server to a target server based

on two categorized of VM migration pattern live VM migration and non-live VM migration. Figure 2.13 shows VM migration pattern-based taxonomy.

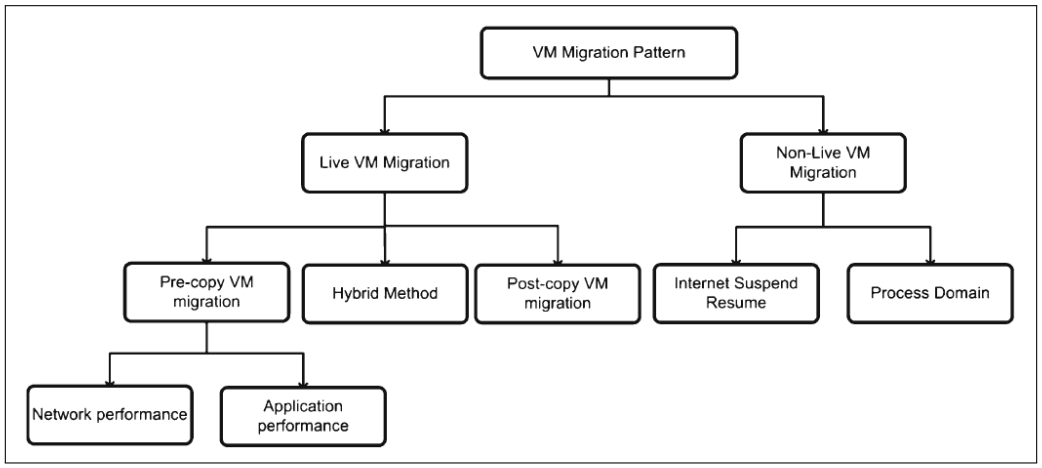


Figure 2.13: VM Migration Pattern [Ahmad et al., 2015]

- Live VM migration provides uninterrupted services during VM migration time via three categories: Pre-copy VM migration, Hybrid Method, and Post-copy VM migration.
- Pre-copy VM migration: the iterative process of copying VM memory pages from source servers to target servers until reaching some termination criterion.
- Post-copy VM migration: the process separated into three phases. In the first, VM execution at source server is suspended then turns to the minimum state to transfer to the target server. The second phases, VM is resumed in the target server. Finally, the memory from source server is copied to target server.
- Hybrid method: the combination of both pre-copy and post-copy method. Non-live VM migration discontinued implementing cause to the advantage of live VM migration. At target server, VMs will not be resumed until completing the migration process lead to degrading the Quality of Service.

When the user's demand suddenly rises during rush hours, by VM migration process, cloud cluster automatically turns from load consolidation to load balancing to guarantee the Quality of Service.

2.2.6 Load Balancing

Load balancing is the process of redistributing the entire workload among compute nodes of the cloud cluster to make resource utilization and improve the response time [Saranya and Maheswari, 2015]. One of primary resource utilization concept is to remove a condition in which some of compute nodes have heavy workload while others are under load or in idle. Depending on system state, load balancing algorithms are classified into two fields: static and dynamic algorithms. On the other hand, if following who initiated the process, load balancing algorithms can be divided into three types as sender initiated, receiver initiated and symmetric [Sahu and Pateriya, 2013].

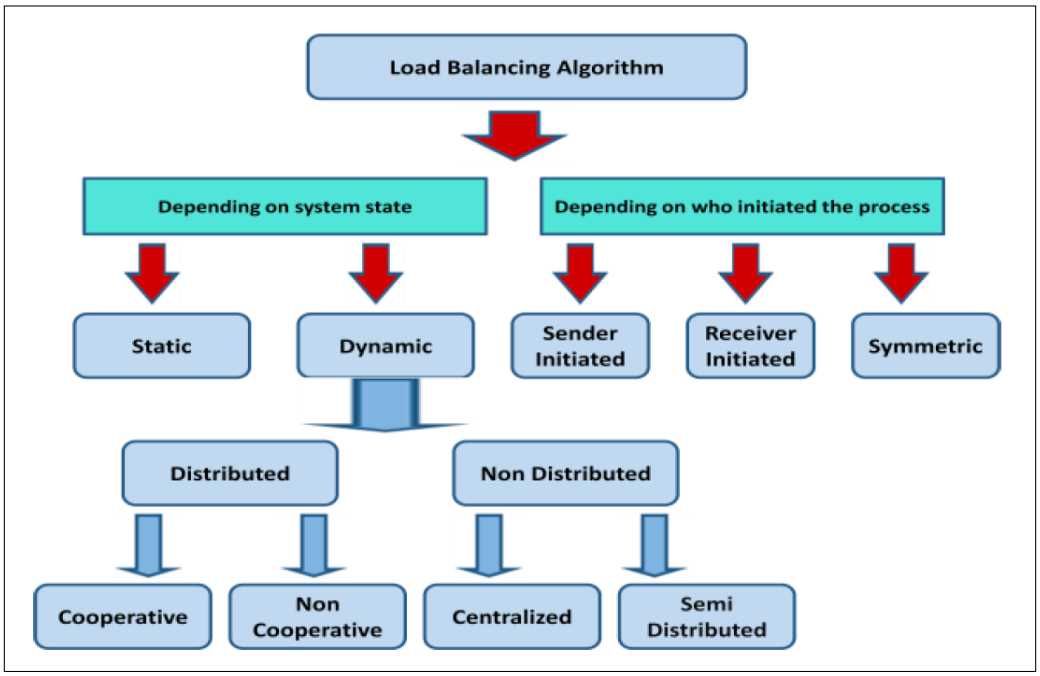


Figure 2.14: Classification of Load Balancing Algorithms [Sahu and Pateriya, 2013]

According to [Hans and Kalra, 2015], based on user demand, there are some measurement parameters to evaluate the load balancing algorithms which are discussed below.

- Throughput: the system can process an amount of a given input in certain of time.
- Response time: It is an amount of time used to execute the user query.
- Fault tolerance: It is the ability that allows the system keep working precisely even any failures are happening.
- Scalability: It is a capacity to expand itself according to required conditions.
- Performance: How the load balancing concept affects the system performance such as reducing the electricity cost, the speed of task execution.

2.2.7 Load Consolidation

The economic model of cloud computing based on the pay-as-you-go model in which providing services by allowing users to design resources and charge by what is used [Feller et al., 2012]. The challenge for providers is to create an energy efficient to handle all their service while meeting the Service-Level Agreement (SLA) which is the contract between vendors and their customers set up to ensure the Quality of Service (QoS). On the other hand, because of the benefit of cloud computing, the growing client demand has led to the cloud provider to increase their data center. This tendency has resulted in huge electricity consumption. The only way to reduce electricity consumption is consolidation process which migrates virtual machines on a certain amount of physical compute nodes as much as possible and set idle compute nodes in power saving state. Hence not used computers consume less electricity then generating less heat, the energy consumption of the cooling system is reduced then power consumption of entire system reduces significantly. Consol-

idation based on live migration, a technique allowing migrating running virtual machines without rebooting operating system inside it. There are three categories of consolidation managers: static and semi-static and dynamic [Han, Que, Jia, and Shu, 2016]. In static consolidation, VMs are expected to live in the host for a long-time period until it has been touched. In semi-static consolidation, live migration is used for creating a cycle of VM migration process in a daily or weekly. Resource utilization of both static and semi-static do not change during execution, the number of reconfigurations according to the process of creation and deletion of VMs. Dynamic consolidation is a possible technique that allows the VM migration would occur at every moment. The figure 2.15 shows four classical steps of load consolidation: monitoring, estimation, reconfiguration and actuation [Feller et al., 2012].

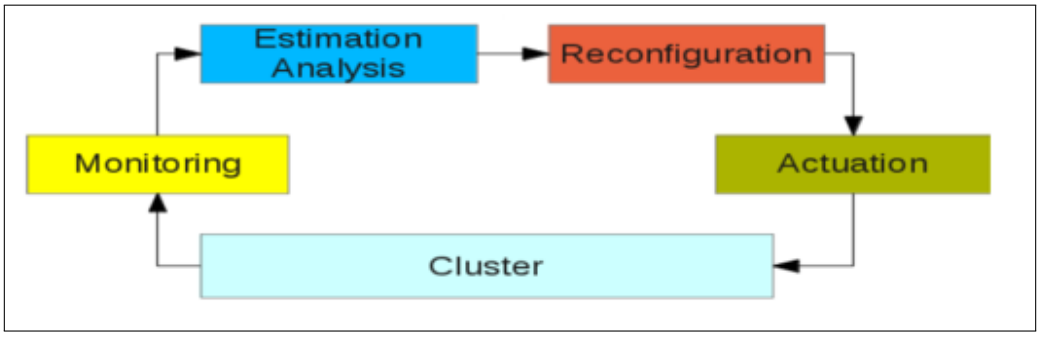


Figure 2.15: Load Consolidation Steps [Feller et al., 2012]

2.3 Related Work

Live migration is a useful technique, but it's still costly and time-consuming, which affects the network performance due to the whole process performance based on network bandwidth. Task-based system load balancing algorithm in cloud computing uses particle swarm optimization which is a new load balancing idea introduced by [Ramezani, Lu, and Hussain, 2014]. The work aims to reduce the downtime, which is a period of time when

a VM is paused from the original host until it is resumed in destination host by migrating extra tasks from overloaded host to underutilized host. The pre-copy VM migration is unnecessary in this approach to eliminate the downtime. However, due to unpredictable incoming tasks to cloud data center, the extra task is hard to control when the system becomes more complex. Otherwise, the system has to find another compatible VM to execute the extra tasks from the overloaded host, which requires building some similarity VMs, and leads to resource wastes such as space of cloud resource.

One of the main challenges of load balancing is it is required to evenly distribute workload across multiple PMs to boost performance and avoid the situation in which two machine exists simultaneously. One machine is executing overloaded tasks when the other is in idle mode or is performing under its capacity [More and Mohanpurkar, 2015]. Partitioning concept is introduced in this work to provide a switch mechanism for choosing different strategies for various situations. The approach applies centralize strategy, which is used in a central machine to gather data then distribute the workload to other partitions. In our approach, we are also using head-node that dynamically receives the request from clients then distributes those requests evenly to every running compute node. The advantage of this strategy is to balance the load between n number of compute nodes before triggering live VM migration processes to optimize CPU's usage of cloud cluster.

Kao et. al [Kao, Cheng, and Kao, 2014] also publish their work on an automatic decision-making mechanism for live VM migration. They present a schema to decide when the system needs to balance workload to guarantee the performance and when it needs a consolidation strategy to utilize energy consumption. Their system will trigger VM migration based on the CPU's usage. However, 80% of CPU's usage which is fixed to make

VM migration decisions might be due to the waste of the resource when the hardware is more powerful today. In addition, because of the fluctuating of CPU's usage during running time, the CPU's usage can go up to 100% in a second then down to 1 - 2% quickly. Their scheme should set up a time to calculate the average of CPU's usage before triggering VM migration.

Figure 2.16 is an example of Green cloud architecture [Liu et al., 2009]. Authors of this structure want to design the power efficiency and effectiveness for online gaming applications hosted in data center environment, achieved by live migration technology. Migration manager triggers live migration and decides on the placement of virtual machines on physical servers based information provided by the Monitoring Service. The Monitoring Service measures including application workload, resource utilization, and power consumption, hence the system can dynamically adapt workload and resource utilization through VM live migration. The Migration Scheduling Engine searches the optimal placement and sends an instruction to execute the VM migration and turn on or off a server. Based on this architecture, unnecessary power consumption in this cloud computing environment is reduced significantly.

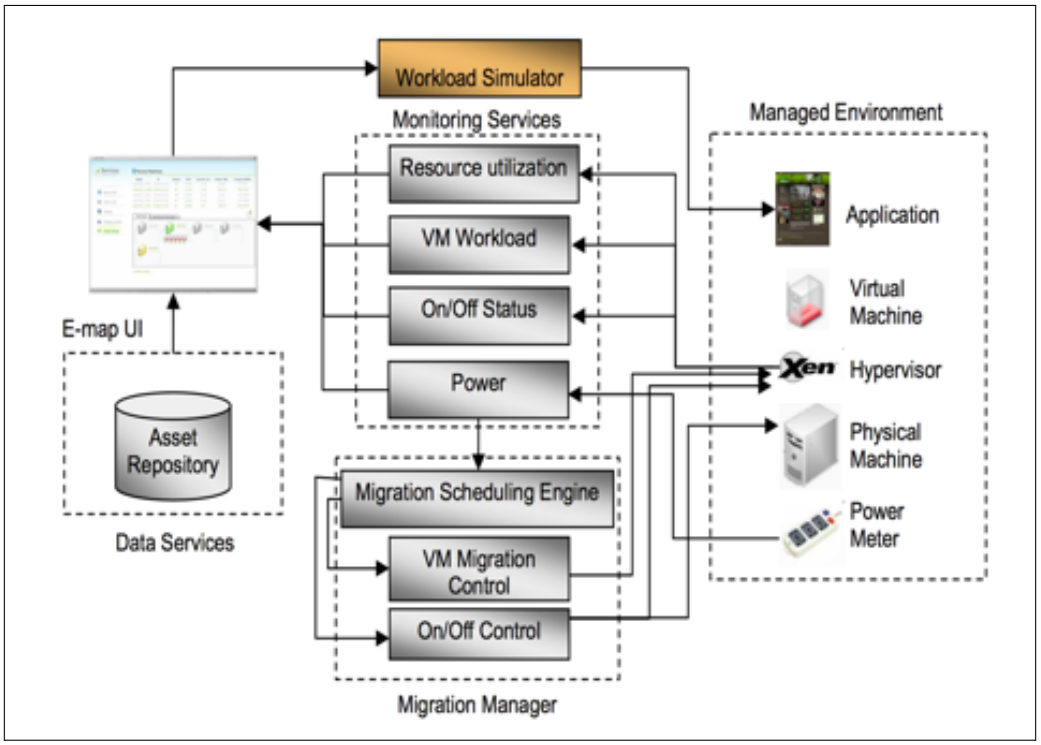


Figure 2.16: Green Cloud Architecture [Liu et al., 2009]

Chapter 3

PROPOSED ARCHITECTURE

3.1 Architecture

A distributed computer system is a set of connected computers that work together in such a way that they could be viewed as a single system. Clustering is mainly used for parallel processing, load balancing, and fault tolerance. Our proposal will be relatively easy to add more power to the cluster by simply adding a new computer to the network. According to [Cisco, 2008], the architecture of server cluster normally consists of a master node which manages other compute nodes. Figure 3.1 is an example of a typical server cluster. The cloud architecture in this study aims to optimize the performance and reduce energy consumption of one cloud cluster in the whole cloud data center. This architecture can be implement in multiple cloud clusters to utilize cloud data center. Applying the similar architecture above, there are three main components in this project: head nodes, storage node and compute nodes.

- Head node: An administrative interface for accessing cloud administrative feature and virtualized resources. It is a connection between VM requirements from users and cloud cluster. It assigns the VM's requests to each compute node based on the load balancing algorithm. It also acts as a bridge between compute nodes when the load consolidation is needed.
- Storage node: nodes used to store persistent user data and VM images. These nodes

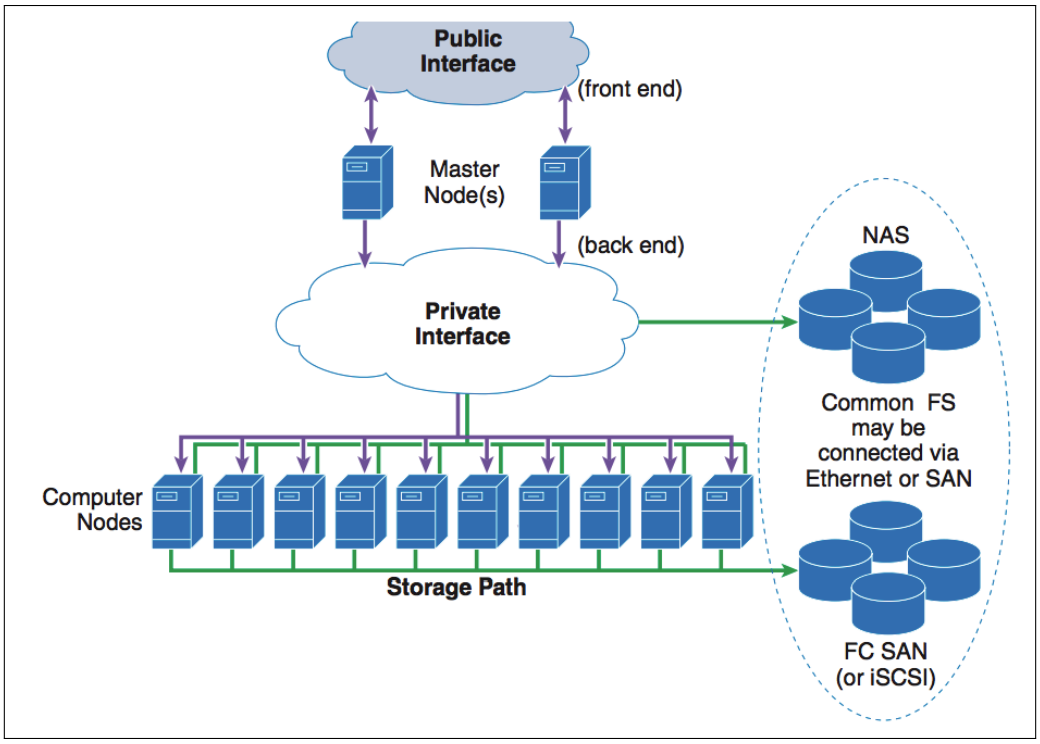


Figure 3.1: Logical View of a Server Cluster [Cisco, 2008]

can replicate data to backup devices to keep data availability high. Otherwise, storage node stores VM images which are launched by compute nodes.

- Compute node: nodes that provides the execution environment for virtual machine instances in Green Cloud. These nodes provide IaaS resources with the help of the KVM hypervisor and Virsh system tools, and can be dynamically scaled based on current demand. Compute nodes have a large capacity computing, so the load balancing and load consolidation algorithm will improve performance more effectively.

Figure 3.2 is an example of our test cloud environment.

3.2 Network Filesystem

Since a shared network is a requirement for implementing live VM migration a research of all network filesystem technique is necessary. In this study, we used "glusterfs"

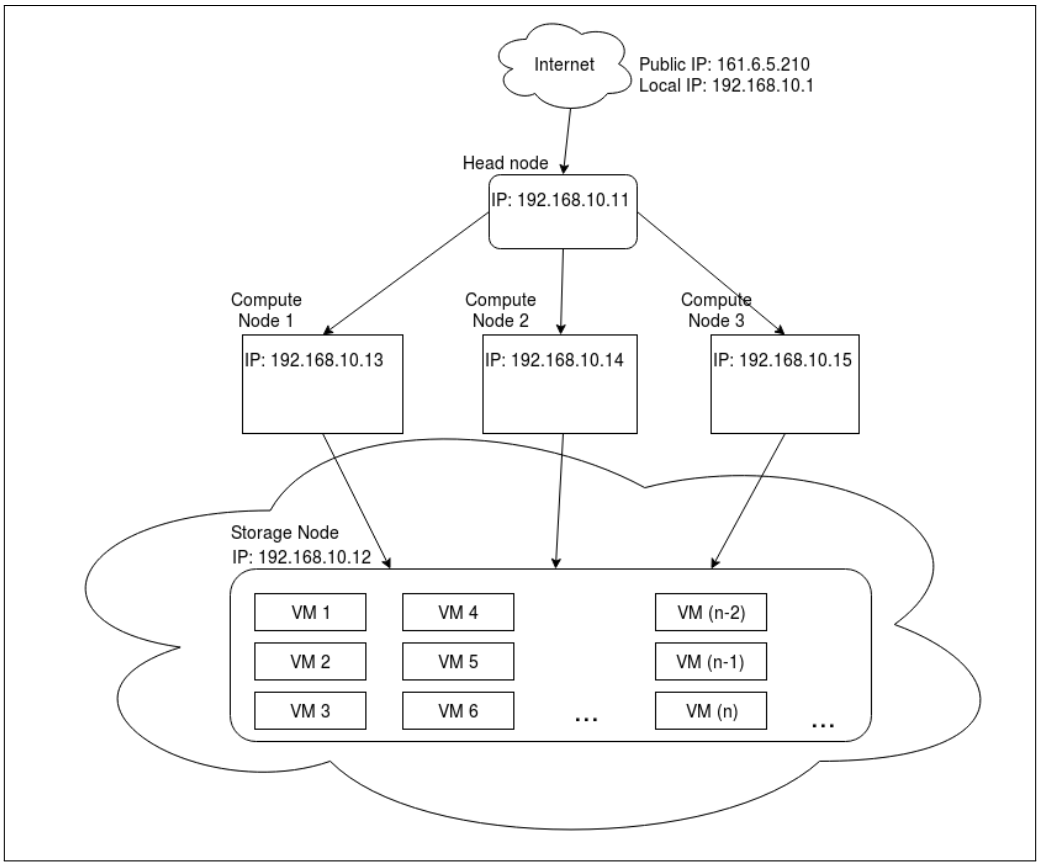


Figure 3.2: My Network Cloud Cluster

an open source which is a scalable network filesystem suitable for data-intensive tasks such as cloud storage and media streaming to perform our cloud environment [Readthedocs.io, 2017]. The concept brick in Glugterfs is defined like any directory on underlying disk filesystem. In GlusterFS, a volume is a combination of bricks from a PM or vary PMs. Glusterfs has five types of volumes which are distributed glusterfs volume, replicated glusterfs volume, distributed replicated glusterfs volume, and striped glusterfs volume. In this research, we implement the distributed glusterfs volume architecture which is the default of glusterfs volume. Files are distributed across various bricks in the volumes in this architecture. The set of bricks includes all redundant spaces in all PMs of our cloud cluster consisting of the head node, storage node, and compute nodes. Following this architecture,

the size of cloud cluster easily scales and speed up. This architecture fit on our research when we aim to optimize a cloud cluster unit in the entire CDC. Although, if a brick fails for a reason, this will lead to complete loss of data, cloud provider always has backup servers to handle a failure to guarantee the QoS. Figure 3.3 is an example of a typical server using distributed volume for the network filesystem.

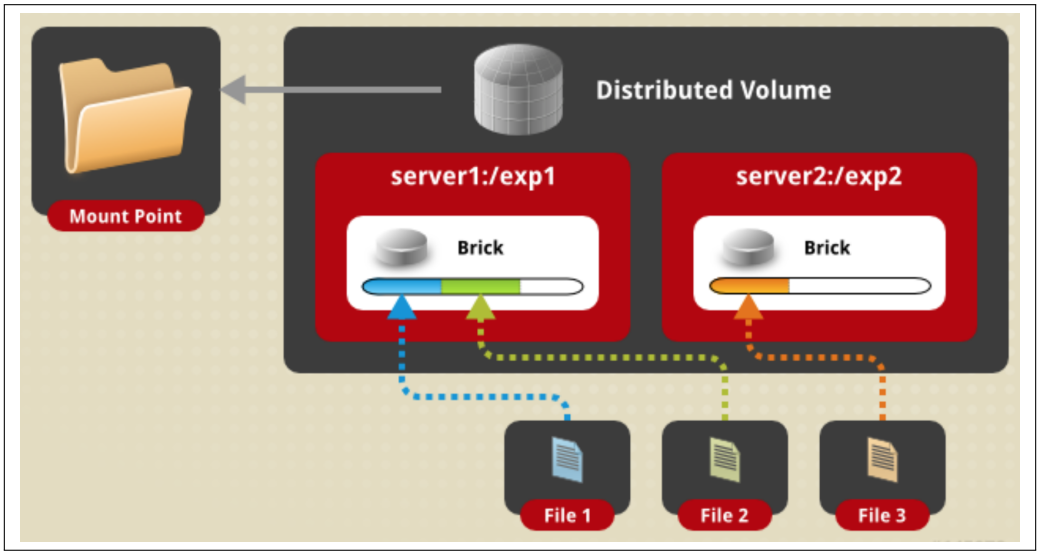


Figure 3.3: Distributed Volume in Glusterfs [Readthedocs.io, 2017]

Chapter 4

LIVE VIRTUAL MACHINE MIGRATION

In this project, I focus on live migration - the method which is moving running VM between two hosts without interrupting the service. Today, there are three kinds of live VM migration including pre-copy VM migration, post-copy VM migration, and hybrid which is the combination of pre-copy and post-copy. Pre-copy is a popular method is using recently.

4.1 Pre-copy VM Migration

According to [Song, Liu, Yin, and Gao, 2014], source host first transfer all memory pages to a destination except dirty pages which are being modified by VM or user. Those pages will be transferred during downtime - the period when VM is paused to migrate. This approach aims to minimize downtime, and the migration process will happen as soon as the number of dirty pages is small. Live VM migration developed by KVM followed this idea consists of 5 steps [Mukhedkar, Chirammal, and Vettathu, 2016]. To deeply understand this approach, I'll point out the main idea of each step below:

Step 1: *Preparing the destination*: At the beginning of live migration process, after the system determines which host needs to migrate VM and another will receive it, libvirt of source host will try to communicate libvirt of the destination host. After the connection is established, standard information of VM which is going to migrate is transferred to the target host. All information will be passed to QEMU to prepare for enabling migration.

Step 2: *Transfer the VM*: In pre-copy, it doesn't transfer the whole VM at one time,

only the parts that are missing at the destination are transferred such as the memory and state of VM. On the other hand, all stuff such as the virtual disk, the virtual network, etc. are available to sync in the destination host. QEMU controls the moving data processes. During this step, the VM is still running on the source host, and the clone is paused. When transferring the memory, the system tries to pass the full memory from the source host to the destination host. Once the most memory is on the target host, QEMU starts transferring the dirty pages of memory which have just been modified by running VM and haven't written yet to the disk. For the running VM, the dirty pages always are there and are modified continuously. There is no way to transfer all dirty pages without pausing the VM. This state will stop until the number of dirty page reaches a low threshold (50 or less) then the system moves to next stage.

Step 3: *Stop the VM at the resource*: At this step, the VM at source host is paused. The synchronous process is triggered at the destination host. Downtime is the period it takes from this stage until the VM is resumed.

Step 4: *Transfer VM state*: At this step, all the remaining dirty pages will be moved to the destination host as soon as possible without any limitation of network bandwidth.

Step 5: *VM continuation*: VM on the target host is resumed. The changing is virtual NICs, and the bridge sends to the network to update hypervisor. After receiving an announcement, data for that VM is passed to the new VM on the destination host. When the whole VM is at destination host, live VM migration is total completed.

4.2 Live VM Migration supported by KVM

To applying live VM migration feature, few requirements needed to be considered:

- The cloud cluster needs to have a shared storage which hosted all VM images using one of the following protocols: iSCSI, NFS, GFS2, FCoE, etc. Our approach uses GFS2 protocol which we discussed in the previous chapter.
- The migration platform and version should be checked the compatibility.
- Both source PM and target PM must have the appropriate TCP/IP ports open.
- A shared storage must mount at the same location on the source and the target server.

After setting up the environment, a guest VM from source PM can be migrated to another host PM with the "virsh" command: $virsh\ migrate --live\ GuestName\ DestinationURL$. When a guest name is the domain name of VM and Destination URL can be the IP addresses or the name of that PM in the/etc/ hosts file.

Chapter 5

DYNAMIC LOAD BALANCING

The motivation of this chapter came from our previous project which was Topper Cloud. The main idea of that project was to provide a virtual lab which could access via web browser. Virtual lab copied all feature from the traditional labs which installed all necessary software for students during college. Instead of going to the lab for research or study, due to the project, students felt more convenient to access to the lab any time or everywhere they want. The project received a lot of good feedback from students except the quality of service because we didn't have proper solutions to design the cloud data center to optimize the performance as well as reduce the energy's consumption to reach the green computing concept. Get a motivation from this, this contribution chapter and the next chapter are our approaches to enhance the server. The following in this chapter are three functions of the load balancer to increase the performance. We also provide the implementation and particular test cases based on the workload simulation to verify the approach.

5.1 Dynamic Load Balancing

Load balancing in cloud computing supports a powerful solution to reach a condition of system optimization. Two main goals of load balancing are scheduling in a distributed environment and resource provisioning [Telkikar et al., 2014]. Scheduling handles the distributed workload from user requests to every PM in cloud cluster and balances

CPU's usage to increase the system performance. Resources provisioning is to guarantee the quality and availability of cloud service by turning on some PMs to handle extra requests in case all running PMs are nearly overloaded.

5.1.1 Distributed Workload

Based on the request VMs from clients, the head node, a server which manages the whole cloud cluster will calculate itself to distribute the whole VM requests to all running computer nodes depending on the capacity and the number running VMs in each computer node. There are few logical steps to be applied in the head node, algorithm 1. First, the controller of the head node will distribute equally VM requests to each PM. Based on the capacity pull out from the database, each PM will try to execute as much as it can the requests. The number of lacking will be sent back to the controller and to be distributed to others in next iteration. After calculating exactly the number of VMs for each PM, the head node will send instantaneous VM requests to all compute nodes at one time. In case

Algorithm 1 Method: *DistributedWorkload()*

```
PMList = check the capacity of each PM from database then poll the available list
maxVMs = the maximum VMs which a PM can hold
busyVMs = running VMs
VMList = poll from database
temporaryDistributedVMRequest = request / number of host
lackVMs = request - temporaryDistributedVMRequest * numberOfPM
for (i=0, len(PMList), 1) do
    freeVM = maxVMs − busyVMs
    if freeVM > temporaryDistributedVMRequest then
        Distribute temporary request to each PM in PMList
    else
        Distribute exactly number of free VMs to each PM in PMList
        Number of lacks will be added to lackVMs
        This PM is removed from PMList
if lackVMs > numberOfPMs then
    Call DistributedWorkload again
else
    Distribute the rest of request even to every PM in PMList
```

all running servers can not handle all the request from clients, the head node needs to turn

on other machines to execute the remaining VM request. Wake-up signals from the head node are sent to servers which are in the save mode. Those servers will be active quickly then post an update data back to the head node. After updating the data of the new server into the database, the head node will send the remaining request to those servers. The detail of those processes we will discuss in the section.

5.1.2 Optimize CPU's Usage

The cloud centers are mostly constituted from heterogeneously servers, which contain a different number of VMs due to fluctuating resource usage. This problem causes to imbalance resource and degrades the performance [Xu, Tian, and Buyya, 2017]. To achieve efficient resource utilization, optimizing CPU's usage of the whole cloud data center is the most challenger for every load balancing algorithms. There are a lot of researchers who focus on this area but most of them do not apply the benefit of live VM migration. Dynamic load balancing which was introduced in [Telkikar et al., 2014] takes more advances than the other. In our approach, the goal is to automatically migrate VMs from one node to others to assure that the workloads on every node are equal or closer. Two primary steps are implemented in this feature consists of: Calculate the load classification and create a migration decision plan.

5.1.2.1 Calculate the Load Classification

The head node will send messages to all running compute nodes to require the CPU utilization. After collecting all data, the controller in the head node will calculate the threshold based on those data to classify all PMs. Next step, the controller will determine the mean by taking the highest CPU utilization subtract the lowest one then dividing the result by two. The difference between the threshold and the mean is used to define the light

and the heavy threshold. Based on light and heavy threshold, the controller classifies the CPU utilization of all PMs into three bands, figure 5.1 and algorithm 2.

- Moderately loaded range is calculated based on adding or subtracting the values which are the difference between the average (L(avg)) and the mean of maximum and minimum to the average.
- Lightly loaded is on the left-hand side of light threshold and heavily loaded is on the right-hand side of heavy threshold.

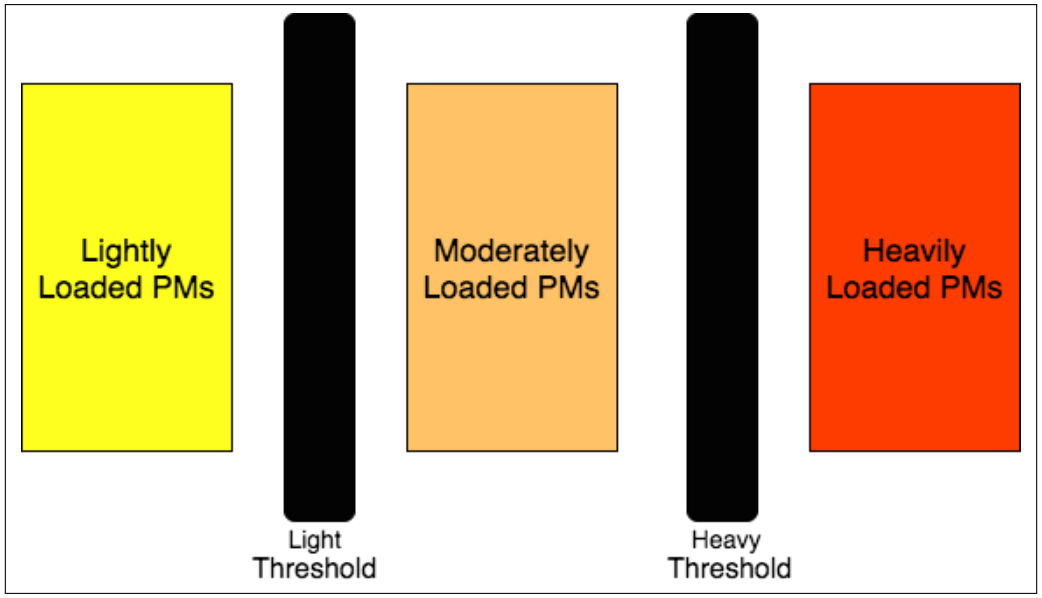


Figure 5.1: Three bands used to classify PMs [Telkikar et al., 2014]

Algorithm 2 Method: *classifyCPU'sLoadOfEachPMs*

$threshold = (u_1 + u_2 + + u_n)/n$
$mean = (u_{min} + u_{max})/2$
$diff = |threshold$ - $mean|$
if diff less than 10 **then**
    $moderdateBandLeft = threshold - diff$
    $moderdateBandRight = threshold + diff$
else
    $moderdateBandLeft = threshold - 10$
    $moderdateBandRight = threshold + 10$

5.1.2.2 Migration Policy

After calculating three bands and classifying all PMs, the system won't change if all PMs belong to the moderately loaded group. Otherwise, migration is triggered when existing at least two PMs: one belongs to the lightly loaded group, and the other belongs to the heavily loaded group. Assuming that the server requires to trigger load balancing for some reasons. There are two considering of load balancing processes in this feature which are: one is to determine a list of PMs which need to migrate its VMs (list 1) to a list of PMs which receive VMs (list 2). Second is to determine which VMs of a PM in the list 1 to PM in the list 2.

Algorithm 3 outlines the idea of our approach choosing the source PM and target PM in the following order. The controller will calculate two parameters which are "the total need" and "the total free" based on comparing the threshold with all PMs in list 1 and list 2. The total needs is a sum of all needs which are the workload of CPU utilization needed to migrate to reach the threshold. In contrast, the total frees is a sum of all frees which are the space between the CPU utilization of PM in list 2 and the threshold. A loop is implemented to migrate some VMs in PMs of list one to PMs of list two following order. In other words, the algorithm will choose PMs from the top to the end of list one to migrate its workload to all PMs in the list two by order. Two cases can happen: a PM in list one migrate to multiple PMs in list two, or a PM in list two receives migration data from various PMs in list one. The loop ends when either total need or total free equal to zero.

After identifying a pair of PMs which need to migrate data and which receives those data, the next consideration is to determine the set of VMs are necessary to be migrated. In

Algorithm 3 Method: *dynamicLoadBalancing()*

```
need = CPU's usage from heavily loaded PM - threshold
free = threshold - CPU's usage from lightly loaded PM
hLoadedPMsList contains all PMs in heavily loaded PM with its need
hLoadedPMsList contains all PMs in lightly loaded PM with its free
totalNeed = sum of need from all PMs in the heavily loaded PM list
totalNeed = sum of free from all PMs in the lightly loaded PM list
while do totalNeed == 0 or totalFree == 0
    for hPM in hLoadedPMsList do
        need = hPM[1] (load need to migrate)
        for lPM in lLoadedPMsList do
            if need == 0 then
                break
            if need greater than free space in lightly loaded PM then
                loadMigrate = free
                listMigrate, needRemain = chooseVM(loadMigrate)
                remove this lightly loaded PM from lightly loaded PM list
                totalFree = totalFree - loadMigrate
                if needRemain less than the lightest CPU's load in hPM then
                    totalNeed = totalNeed - loadMigrate
                    break
                else
                    totalNeed = totalNeed - loadMigrate + needRemain
            else
                loadMigrate = need
                listMigrate, freeRemain = chooseVM(loadMigrate)
                Update free resource to the lightly loaded PM
                totalFree = totalFree - loadMigrate
                totalNeed = totalNeed - loadMigrate
                break
```

other words, with a specific workload of each PM in list one, the PM needs to determine the best set of VMs of it to migrate which the sum of it is the closest to the workload discuss above. Algorithm 4 is our approach to solve this requirement. The first step, the controller will sort the collection of CPU utilization from high to low. Next, a "while" loop is called to scan the list from left to right. In the scenario that the "need" is higher than the virtual CPU utilization of VM so that VM will be added to the migration list and calculate the new "need" by subtracting the need to the virtual CPU utilization. The loop halt when the need is equal to zero or it lesses than lowest virtual CPU utilization which means that this PM does not need to migrate any VMs to reach the threshold. Additionally, the method accepts

to migrate a VM which has virtual CPU utilization higher than the "need" 5% to handle the unstable of CPU. For instance, a PM needs to migrate 10%, but the lowest virtual CPU's usage is 15%, the migration policy accepts to migrate in this scenario.

Algorithm 4 Method: *chooseVMs(PM,loadMigrate)*

```
Sort VMs following by CPU's usage and label the position to recall late
loadRemain = loadMigrate
for i in range( numberOfVM - 1,-1,-1)  do
    Scan list from the right to the left
    if CPU's usage greater than (loadRemain + 5) then
        continue
    if CPU's usage less than (loadRemain + 5) then
        Allow to migrate load which is greater than 5 percent of the capacity
        Add this VM to migrate list
        loadRemain = loadRemain - CPU's usage of this VM
    if the loadRemain less than the smallest CPU load of VM in the list then
        loadRemain = 0
        break
return listMigrate,loadRemain
```

5.1.3 Resource Provisioning

The load balancing algorithm may need to handle two extreme scenarios: One, for some reasons some VMs suddenly receive a heavy workload lead to rising quickly CPU's usage of the PM up to the high performance and stays there for a period of time. To guarantee the quality of service, the PM needs to communicate with the head node (the controller) to require VM migration by updating the overloaded list which is a queue created by head-node. This queue is kept empty and is shared by all nodes in cloud cluster. Each PM will detect overload itself then update this queue. Head-node checks this queue frequently then makes migration decision. Free PM is captured from the list of free PMs (represented by a stack). Similarly, each PM also updates this list by itself. Head-node chooses PMs to host the VM from the overloaded PM by picking up the first PM in the *freePMs* list. The other scenario is when the head-node distributes the VM requests to a

busy cloud cluster when all PMs consumes almost all of its capacity. It means that head-node is unable to find a new PM to distribute the request then the system has to expand their cluster to assume the quality of service. The head-node will send turn-on signal to new PM then distributes VM request to those machines. The information of that machine is updated to list of free PMs. Figure 5.2 describes the processes to handle those extreme scenarios.

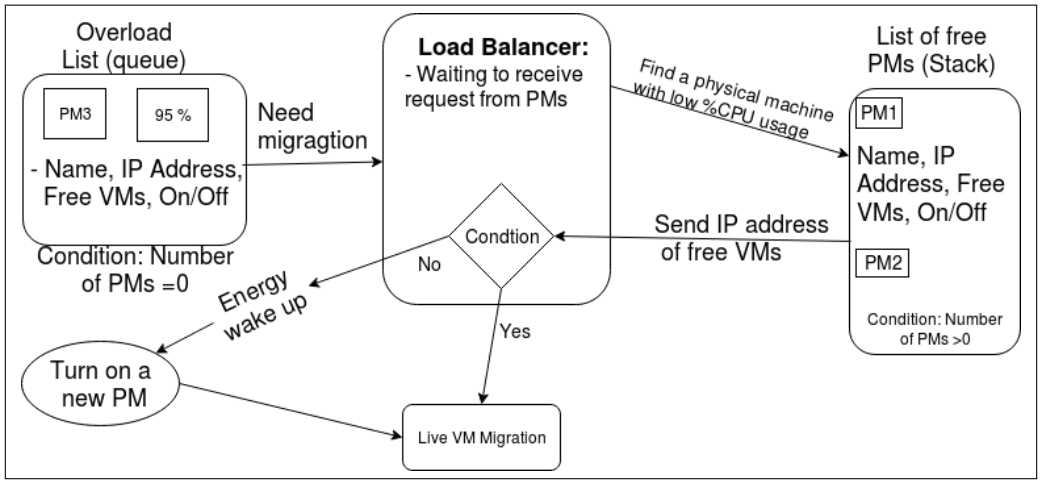


Figure 5.2: Resource Provisioning

5.2 Implementation and Results

This section explains how we simulated workloads of a cloud data center and implemented load balancing on our cloud cluster. To verify our algorithm, we assume that our approach supports to the cloud data center which serves the virtual lab for the college students. The simulation workload of each virtual CPU represents the CPU's usage to perform the software running inside VMs creating by the student. The CPU's usage data we collected from each PM used to run our load balancing algorithm. The following sections indicate the way we set up the cloud environment and four test cases were applied.

5.2.1 Cloud Environment Setup

5.2.1.1 Implement Live Migration:

QEMU-KVM: an open-source hypervisor used to generate and manage VMs. Glusterfs: an open-source which is used to create a brick in storage node to store images of all VMs in cloud cluster. The brick can be accessed by every node. After the cloud environment is setup, live migration can be executed by *migrate* command port and destination IP address as its parameters.

5.2.1.2 The initial state of the Green Cloud:

First step is to guarantee the cloud environment is established. Next step is to turn on a group of PMs in the cloud cluster including the head node, the storage node, and at least one compute nodes. After turning on the head node, a thread runs continuously to capture the date from other computers to update the information of all running servers into the database. This info comes from every server, after turning on a new server, this server will send an update data request to the head node which covers the number of CPU's core, the maximum number of VMs, the MAC address, the role of this server and the flag which support the head node identify this request. After receiving the update confirmation from the head node, all compute nodes will be turned to save mode or turn off and waiting for a wake-up request from the head node.

5.2.1.3 Hardware and some Limitations of Test Cases:

To implement my load balancing algorithm, the hardware I used for testing case consists of five similar. One is designed as a head node which will handle all tasks of the

cluster; another has extra space which represents as storage node. The others are compute nodes which mainly execute tasks.

5.2.2 Distributed Workload Implementation

In this project, we assume that the Head-node receive 12 VM requests from client. Figure 5.3 shows the distributed workload when controller tries to execute the requests to all compute node which it's controlling. Based on the capacity of node 1, it cannot handle more than three additional VMs. One VMs request is returned back to the controller to be distributed to compute node 2 or compute node 3 in the next iterative loop.

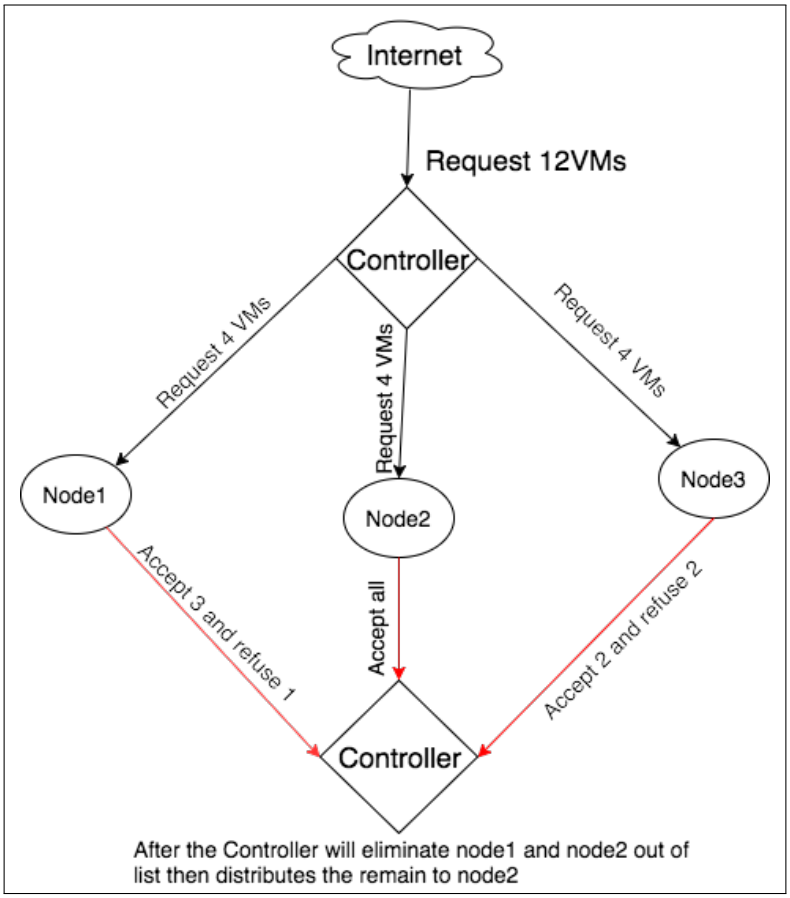


Figure 5.3: Workload Distribution

5.2.3 Optimization of CPU's usage

There are several steps implemented following by order:

1. Gather CPU's usage in all Compute-node.
2. Calculate three loaded group based on the threshold.
3. Assign every Compute-node to the adequately loaded group.
4. Find the list of VMs needed to migrate.
5. Implement Live Migrate and calculate migration time.
6. Gather CPU's usage of all Compute-node to verify the algorithm.

There are several ways to simulate the CPU's usage on every VMs. In this research, we use "stress-ng" an open-source to which allows us to set a random number of CPU's usage to each VMs. The syntax is "$stress-ng-c\ 0-l(CPU\_workload)$". Following this syntax, an operating system will generate a simulation word load then distribute it to all cores of the PM. To capture the CPU's usage of each VM running on a host, "libvirt", a library of KVM, support a command line to calculate CPU times of each virtual CPU running on the real CPU. The syntax is "$virshcpu-statsdomain_name--total$". Based on the CPU time, we calculate the percentage of CPU's usage following by taking CPU time divide to the total resource availability time. For example, recording the CPU time between 5 seconds, the CPU percentage equals "$(CPU\_time\_2-CPU\_time\_1)*100/5$".

There are four test cases implemented which are:

- Existing three PMs with a different type of CPU's usage including one is in the light workload, another is producing the average workload, and the other is with the massive workload.
- All PMs are running under their CPU's capacity.

- All PMs are processing near their CPU's capacity.
- All PM belong to moderately workload group

In order to assess the performance of the algorithm, a prototype system of VM management was developed. The virtual platform used in this study was KVM. Glusterfs, an open source, was used to make the connection between all servers. The OS used to test was Ubuntu 16.04. There were five computers, which had the same capacity, used to test the performance of load balancing algorithm. We used "Top" command to get the CPU's usage of each compute node. We also utilize the feature of "$libvirt-kvm$" which is "cpu_stats" to calculate of vCPU's usage of each VM. Finally, "$stress-ng$", an opened-sourced, was used to simulate the CPU's usage of every VMs. There is four test cases were applied in this study: (1) Mixed, (2) Most of PMs are in the underutilized workload, (3) Most of PMs are in highly performance, (4) Most of PM belong to moderately workload band. Following

Compute node	CPU of Host	List VM	Note
Node1 before migrating	58.15%	N1VM1 –> N1VM5: (10,30,40,60,80)	Moderately Loaded
Node2 before migrating	16.72%	N2VM1 –> N2VM5:(10,10,20,20,10)	Lightly Loaded
Node3 before migrating	84.09%	N3VM1 –> N3VM5: (70,40,60,80,90)	Heavily Loaded
Node1 after migrating	56.27%	Not change	Moderately Loaded
Node2 after migrating	51.13%	Add N3VM2, N3VM5 from Node3	Moderately Loaded
Node3 after migrating	52.99%	Migrate N3VM2, N3VM5 to Node2	Moderately Loaded

table 1 and graph 5.4, we tested all PMs which have a random number of VMs and weight. If a PM belongs to moderately workload group that PM will be touched. Otherwise, based on the choosing VMs function, VMs from the heavy one are migrate to the light one. The load balancing processes stop when no existing one PM in heavy workload group and one PM in the light workload group simultaneously. Following the test case, all PM belong to the moderate workload group after implementing load balancing. In test case 2, we test the scenario that almost PMs are underutilized, and one PM is overloaded. The load balancing

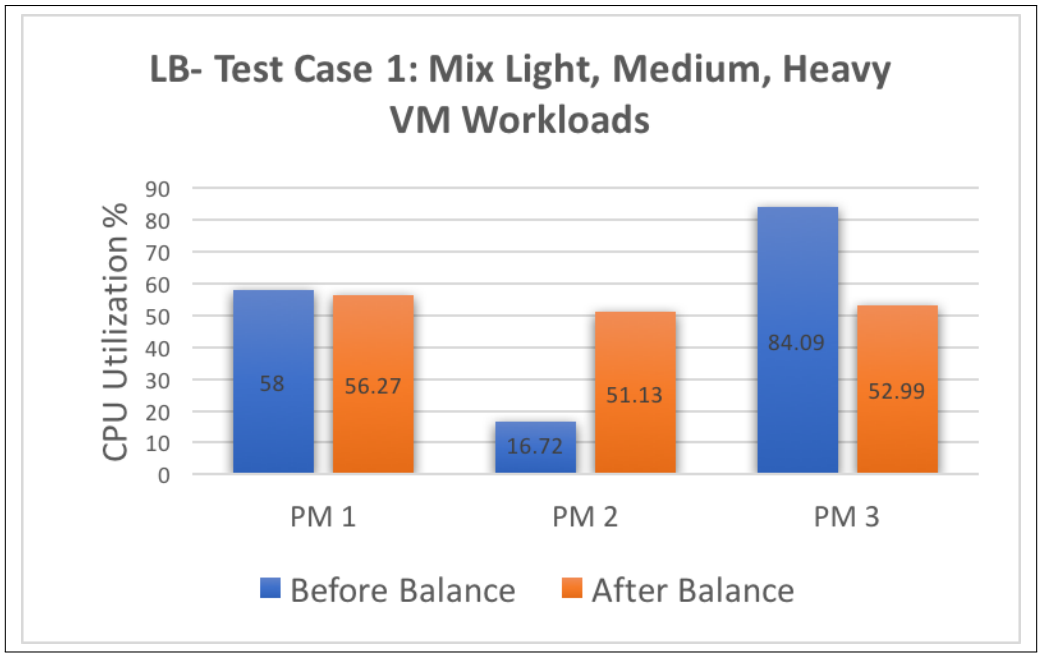


Figure 5.4: LB -Test Case 1: Mixed VM Workloads

Compute node	CPU of Host	List VM	Note
Node1 before migrating	4.64%	N1VM1 –> N1VM2: (5, 10)	Lightly Loaded
Node2 before migrating	5.08%	N2VM1 –> N2VM3:(10,10,5)	Lightly Loaded
Node3 before migrating	92.34%	N3VM1 –> N3VM5: (60,80,80,90,90)	Heavily Loaded
Node1 after migrating	44.43%	Receive N3VM1, N3VM5 from Node3	Moderately Loaded
Node2 after migrating	24.16%	Receive N3VM3 from Node3	Lightly Loaded
Node3 after migrating	42.86%	Migrate N3VM1, N3VM3 and N3VM5	Moderately Loaded

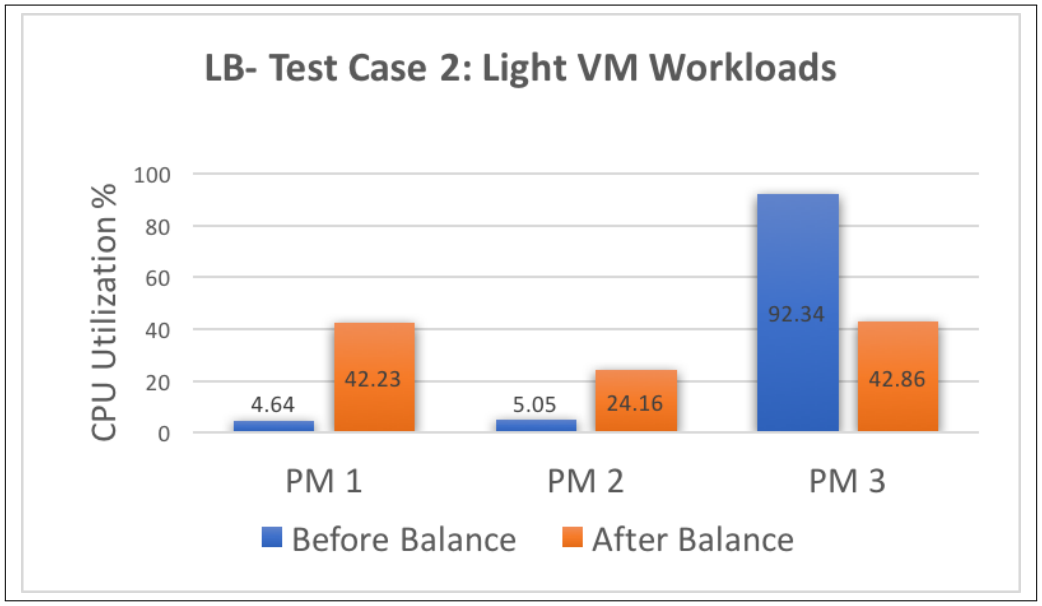


Figure 5.5: Dynamic Load Balancing - Light Workload

plan indicates that most VMs from the heavy PM needed to migrate to the light one. The result shows that most PMs belong to the moderate workload group except one PM which belongs to light workload. This scenario happens when the remaining VMs in the original host are too big to fit the light one. In test case 3, most of PM stay in high performance,

Compute node	CPU of Host	List VM	Note
Node1 before migrating	94.85%	N1VM1 –> N1VM5: (90,60,80,90,90)	Heavily Loaded
Node2 before migrating	65.08%	N2VM1 –> N2VM3:(90,90,80)	Moderately Loaded
Node3 before migrating	91.60%	N3VM1 –> N3VM5:(60,80 80 90,90)	Heavily Loaded
Node1 after migrating	83.33%	Migrate N1VM3	Heavily Loaded
Node2 after migrating	88.86%	Add N1VM1 from Node1	Heavily Loaded
Node3 after migrating	91.75%	No change	Heavily Loaded

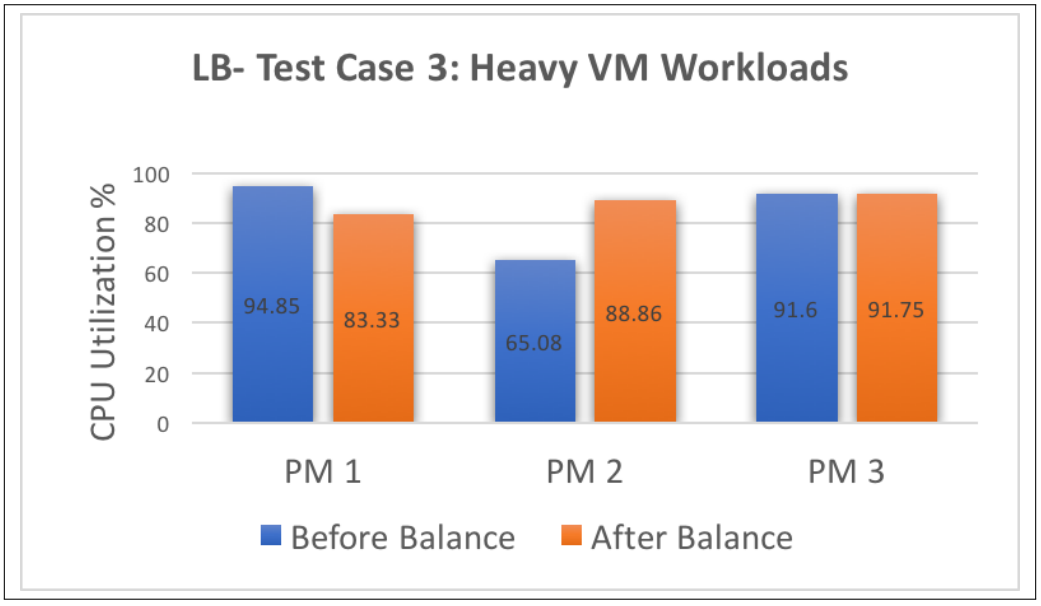


Figure 5.6: LB - Heavy Workload

depending on the weight of VMs of the PM with highest CPU utilization, VMs from this PM can be migrated to others lower CPU utilization to balance the CPU utilization of entire cloud cluster. The result shows that a VMs from Node 1 is migrated to Node 2 based on the balancing process. The last test case including figure 4 and figure 5.7 is on the scenario in which most of PMs stay in the moderate workload group. The result shows that some of

Compute node	CPU of Host	List VM	Note
Node1 before migrating	37.25%	N1VM1 –> N1VM3: (40,60,50)	Moderately Loaded
Node2 before migrating	4.01%	N2VM1 –> N2VM2:(10,50)	Lightly Loaded
Node3 before migrating	44.57%	N3VM1 –> N3VM3:(60,60,60)	Moderately Load
Node1 after migrating	33.29%	No change	Moderately Load
Node2 after migrating	29.46%	Add N3VM3 from Node3	Moderately Loaded
Node3 after migrating	30.04%	Migrate N3VM3 to Node2	Moderately Loaded

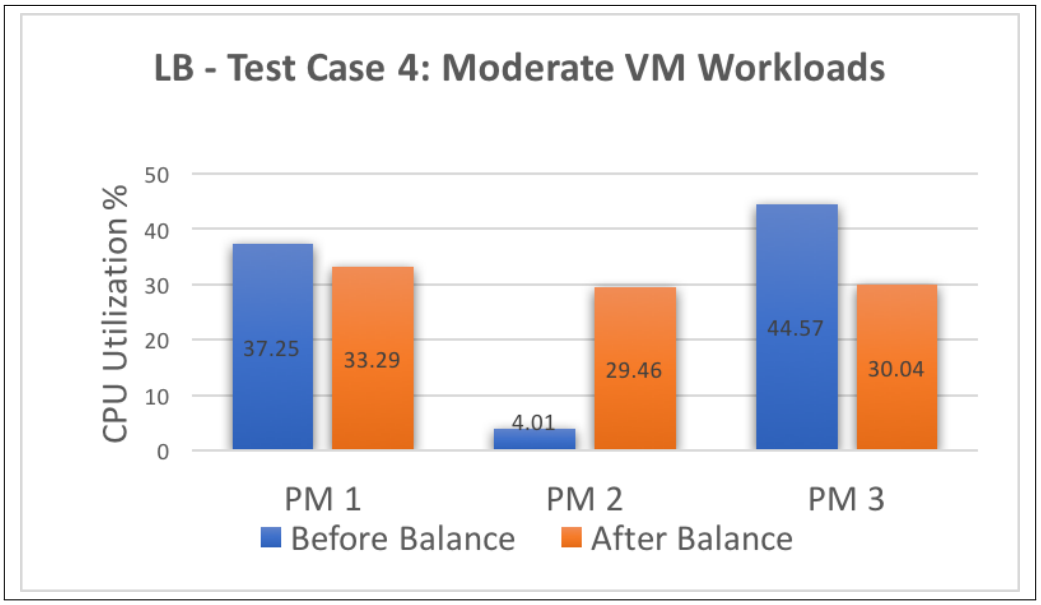


Figure 5.7: Dynamic Load Balancing - Moderate Workload

VMs from the CPU with higher CPU utilization are migrated to the one with lower CPU utilization to reduce the CPU utilization of the entire cloud cluster.

Chapter 6

LOAD CONSOLIDATION

Cloud data centers become more attractive because of they offen costs less than traditional server due to virtualization technology. Although its performances are more advanced than the previous, it still consumes a tremendous energy due to rapidly growing user demand. Following [Sekhar, Jeba, and Durga, 2012], [Ferdaus, Murshed, Calheiros, and Buyya, 2014], [Farahnakian, Ashraf, and Pahikkala, 2014], 55% of costs in a data centers were to power 10-15% of all servers running at full capactiy. Moreover, due to pay-as-you-go business model, the users shift the investment risk for under, or over-provisioning to cloud provider where they handle the concern of fluctuating utilization. So, to increase the annual revenue, the major concern of cloud provider is to design an energy-efficient data center. From [Sekhar et al., 2012], this problem has been approached from various perspectives: (1) Energy efficient hardware architecture, (2) virtualization of computing resources, (3) energy-aware job scheduling, (4) dynamic voltage and frequency scaling, (5) server consolidation, and (6) switching off unused nodes. In this project, we mainly focused on server consolidation, creating an algorithm which packs all client requirements into as minimal PMs as possible to reduce energy consumption without violating SLA policies. By setting the static threshold calculated by CPU's usages of all servers in cloud cluster to 85% to guarantee the QoS. So, no PM is found over-utilized under consolidation algorithm [Sami, Haggag, and Salem, 2015]. In the previous chapter, I mentioned system

provisioning feature which allows expanding the system capacity automatically to assure SLA policies. In this contribution chapter, I concentrate on how to minimize the number of PMs to handle VM requests.

6.1 Bin Packing Problem

One dimensional bin packing problem is an NP-hard combination optimization problem based on the partition problem. Give a list including "n" items with weight "w" the question is how to pack to as few bins as possible. Load consolidation method also encounters this problem when the system tries to consolidate all running servers based on the CPU's usage. There are several solutions introduced to solve this problem such as Next Fit, First Fit, Best Fit, First Fit Decreasing, etc.

- Next Fit is the simplest one. The algorithm just merely scans all items and try to fulfill bins following by order. The time complexity is O(n^2). The number of containers in this algorithm is not optimized.
- First Fit: The algorithm places the items in the order way in which they arrive. For adding next item, this approach will search all opening containers. The first possible container found will receive this item. In case, the item does not fit with any container; a new container is added to the system to store this item. The time complexity is O(n^2).
- First Fit Decreasing is an optimization of the first fit when the input is sorted before applying the first fit algorithm. This algorithm has better performance in which reducing time complexity which is O(nlog n) and getting a better result. Example: Given

the set of S = 4,8,5,1,7,6,1,4,2,2 and the bins size of 10. Figures 6.1, 6.2, 6.3 apply the first fit, the next fit and the first fit decreasing algorithm into as few bins as possible.

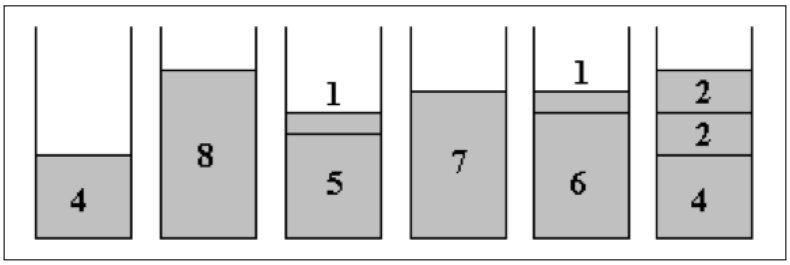


Figure 6.1: Next Fit algorithm

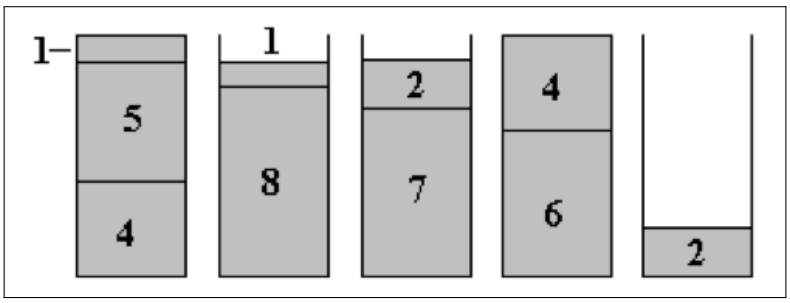


Figure 6.2: First Fit algorithm

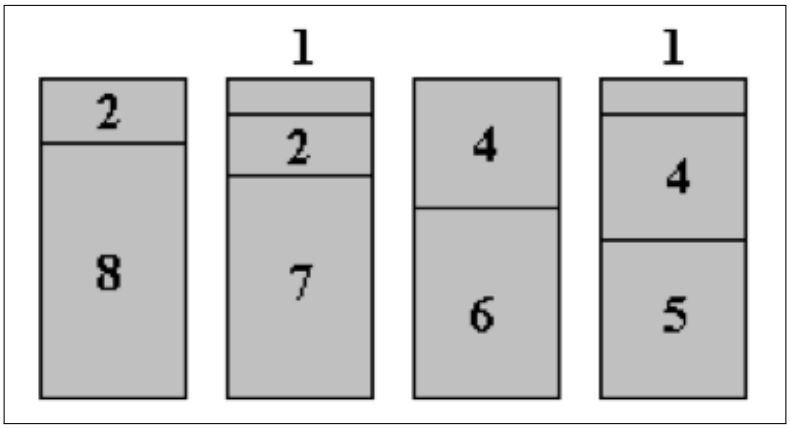


Figure 6.3: First Fit Decreasing Algorithm

6.2 My Approach for Load Consolidation

Bin packing problem not only happens when finding the best way to ship items with different weight but this problem is recalled when applying load consolidation to pack all VMs into less PMs. In this study, based on the idea of First Fit Decreasing algorithm, we

designed a similar algorithm to consolidate the cloud servers based on the CPU's usage. Algorithm 5 is the pseudo code of our solution to consolidate the cloud servers.

Algorithm 5 Method: firstFitDecreasing(list vCPU usage, number of PM, max CPU's usage)

```
check CPU's usage of every PM, eliminate PMs in which its CPU's usage > 85%
label all VMs which indicates the previous host before migrating
sort all VMs following decreasing order
migrationPlan = []
list new PMs = [number of PM]
Set all PMs in list new PMs = max CPU's usage
number of PM after consolidation = 0
for (i=0, len(list vCPU usage), 1) do
    for j = 0, j < number of PM after consolidation, 1 do
        if list new PMs[j] > list vCPU usage[i] then
            list new PMs[j] = list new PMs[j] - list vCPU usage[i]
            migrationPlan.append(name of original host, index of VM)
    if j == number of PM after consolidation then
        list new PMs[j] = list new PMs[j] - list vCPU usage[i]
        number of PM after consolidation ++
        migrationPlan.append(name of origional host, index of VM)
return migrationPlan
```

6.3 Test Cases and Results

In this contribution chapter, we used the same technique when testing the load balancing algorithm's performance. There is four test cases were applied in this study: (1) Mixed, (2) Most of PMs are in the underutilized workload, (3) Most of PMs are in highly performance, (4) Most of PM belong to moderately workload band. In the test case 1 and

```
1
2       Compute node      | CPU of Host |          List VM
3
4  Node1 before migrating | 85%         | N1VM1 -> N1VM5: (70,40,60,80,90)
5  Node2 before migrating | 65.09%      | N2VM1 -> N2VM3:( 90,90,80)
6  Node3 before migrating | 92.34%      | N3VM1 -> N3VM5: (60,80,80,90,90)
7  Node4 before migrating | 5.08%       | N4VM1 -> N4VM3:( 10,10,5)
8  Node5 before migrating | 4.64%       | N5VM1 -> N5VM2: (10,5)
9
10 Node1 after migrating     | 84.09%      | No change
11 Node2 after migrating     | 74.82%      | Receive all VMs from node4 and node 5
12 Node3 after migrating     | 91.2%       | No change
13 Node4 after migrating     | 0%          | Turn Off
14 Node5 after migrating     | 0%          | Turn Off
```

Figure 6.4: LC - TB 1: Mix VM Workload

figure 6.5, we had a set of PM with random CPU utilization. The PM set we had which consists of two heavy, two light and one moderate workload. The results showed that we

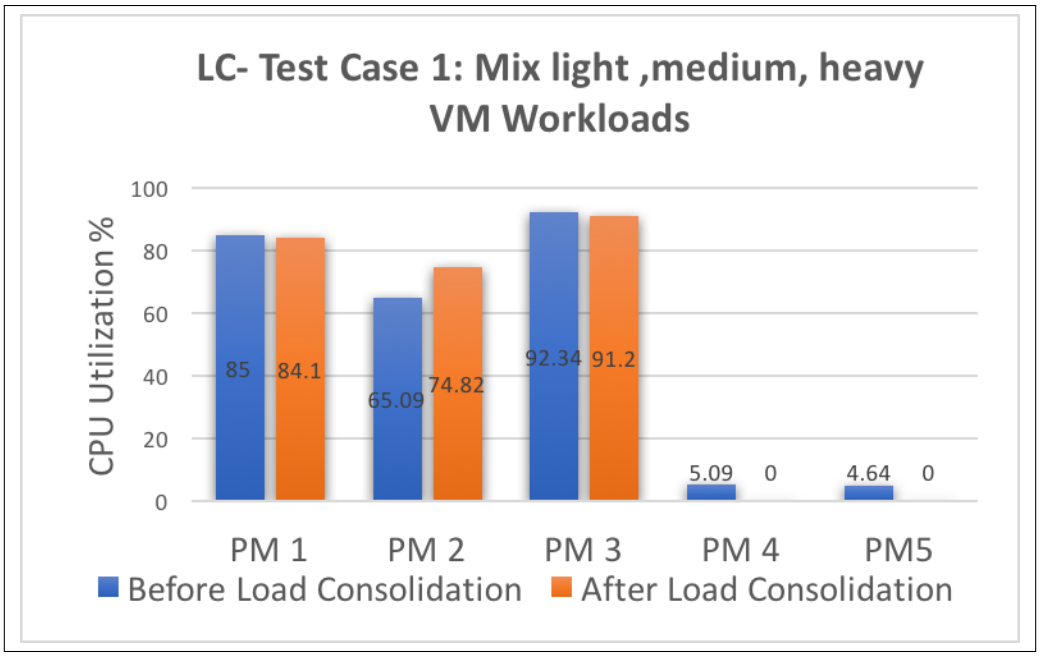


Figure 6.5: LC - Test Case 1: Mix VM Workload

could consolidate the system into three PMs and the remaining was turned off or switched to lower power. In this test case 2 and figure 6.7, we assumed that almost PMs in the cloud

```
1
2        Compute node      | CPU of Host |          List VM
3
4  Node1 before migrating  | 16.72%      | N1VM1 -> N1VM5: (10,10,20,20,10)
5  Node2 before migrating  | 15.8%       | N2VM1 -> N2VM5:(10,10,20,20,10)
6  Node3 before migrating  | 5.09%       | N3VM1 -> N3VM3: (10,5,5)
7  Node4 before migrating  | 4.64%       | N4VM1 -> N4VM2:( 10,5)
8  Node5 before migrating  | 17.28%      | N5VM1 -> N5VM5: (10,10,20,20,10)
9
10 Node1 after migrating     | 59.531%     | Receive all VMs from other nodes
11 Node2 after migrating     | 0%          | Turn Off
12 Node3 after migrating     | 0%          | Turn Off
13 Node4 after migrating     | 0%          | Turn Off
14 Node5 after migrating     | 0%          | Turn Off
```

Figure 6.6: LC - TB 2: Light VM Workload

cluster were underutilized. The result showed that the PM which had the highest CPU utilization took all VMs from other nodes. Other nodes after this processes were turned to lower power or turned off. In test case 3 and figure 6.9, we tested our algorithm in a situation when most of PMs were handling the moderate workload. After implementing our algorithm, we had three PMs were in high CPU utilization, one PM was in underutilizing, and one PM was turned off. In the last test case 4 and figure 6.11, we tested the situation

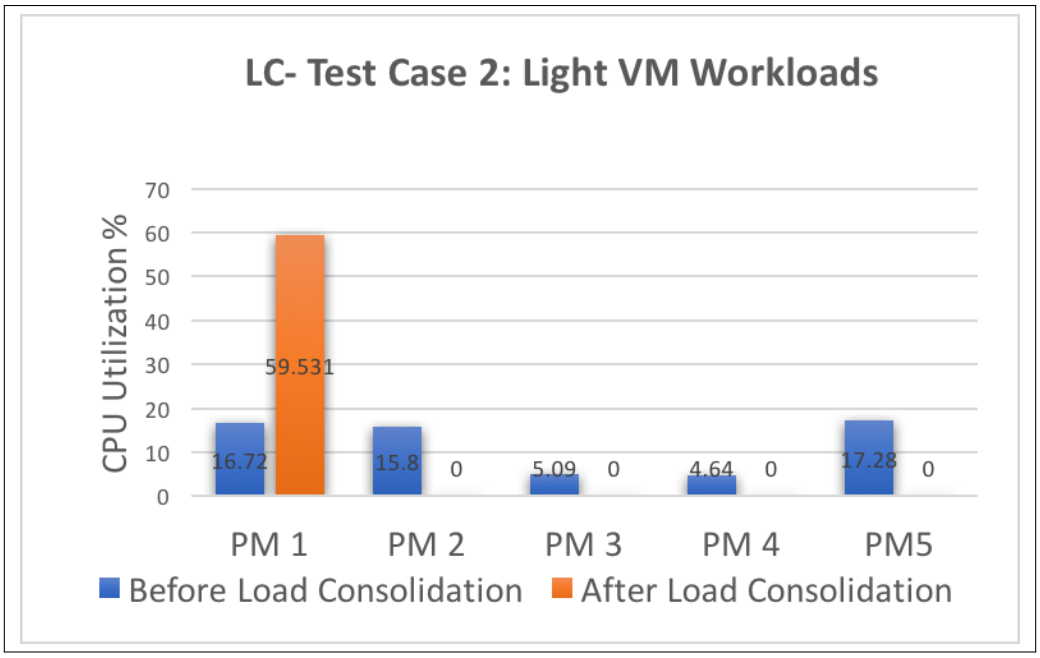


Figure 6.7: LC - Test Case 2: Light VM Workload

Compute node	CPU of Host	List VM
Node1 before migrating	58.15%	N1VM1 –> N1VM5:(10,30,40,60,80)
Node2 before migrating	65.08%	N2VM1 –> N2VM3:(90,90,80)
Node3 before migrating	37.25%	N3VM1 –> N3VM3:(40,60,50)
Node4 before migrating	44.57%	N4VM1 –> N4VM3:(60,60,60)
Node5 before migrating	46.6%	N5VM1 –> N5VM3:60,60,60)
Node1 after migrating	84.71%	Receive some VMs from node4 and node5
Node2 after migrating	81.525%	Receive some VMs from node4 and node5
Node3 after migrating	78.494%	Receive some VMs from node4 and node5
Node4 after migrating	7.93%	Migrate some VMs to other nodes
Node5 after migrating	0%	Turn Off

Figure 6.8: LC - TB 3: Moderate VM Workload

when most PMs were in high performance. Consolidating on this matter was hard. However, our algorithm still impacted on PMs which had CPU utilization less than 85%. The algorithm tried to rearrange the VM placements to get better consolidating CDCs. Figure 6.12 indicates the trade-off between CPU utilization and energy consumption. We used Watts-up, a watt electricity usage monitor, to measure the energy consumed by the changing of CPU's workload. According to the data collected from Watts-up, energy's usage curve tend to increase quickly when the CPU's workload changes from idle to medium. In contrast, energy's usage grows slowly when CPU directs toward to high utilization. Fig-

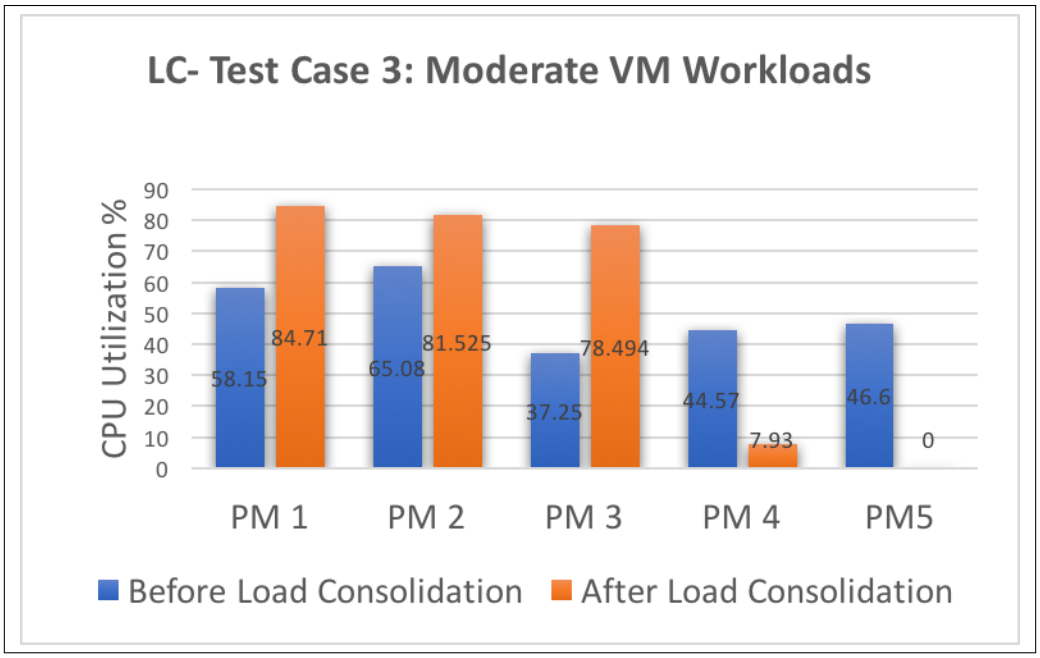


Figure 6.9: LC - Test Case 3: Moderate VM Workload

```
1
2        Compute node      | CPU of Host |          List VM
3
4  Node1 before migrating  | 84.09%      | N1VM1 -> N1VM5:(10,30,40,60,80)
5  Node2 before migrating  | 94.85%      | N2VM1 -> N2VM3:(90,90,80)
6  Node3 before migrating  | 81.6%       | N3VM1 -> N3VM3:(40,60,50)
7  Node4 before migrating  | 3.2%        | N4VM1 -> N4VM3:(60,60,60)
8  Node5 before migrating  | 65.08%      | N5VM1 -> N5VM3:60,60,60)
9
10 Node1 after migrating     | 84.71%      | No change
11 Node2 after migrating     | 93.2%       | No change
12 Node3 after migrating     | 79.74%      | No change
13 Node4 after migrating     | 0%          | Turn Off
14 Node5 after migrating     | 69.62       | Receive VMs from Node4
```

Figure 6.10: LC - TB 4: Heavy VM Workload

ure 6.13 illustrates the total energy saving of a cloud cluster gained after apply our load consolidation on four test cases.

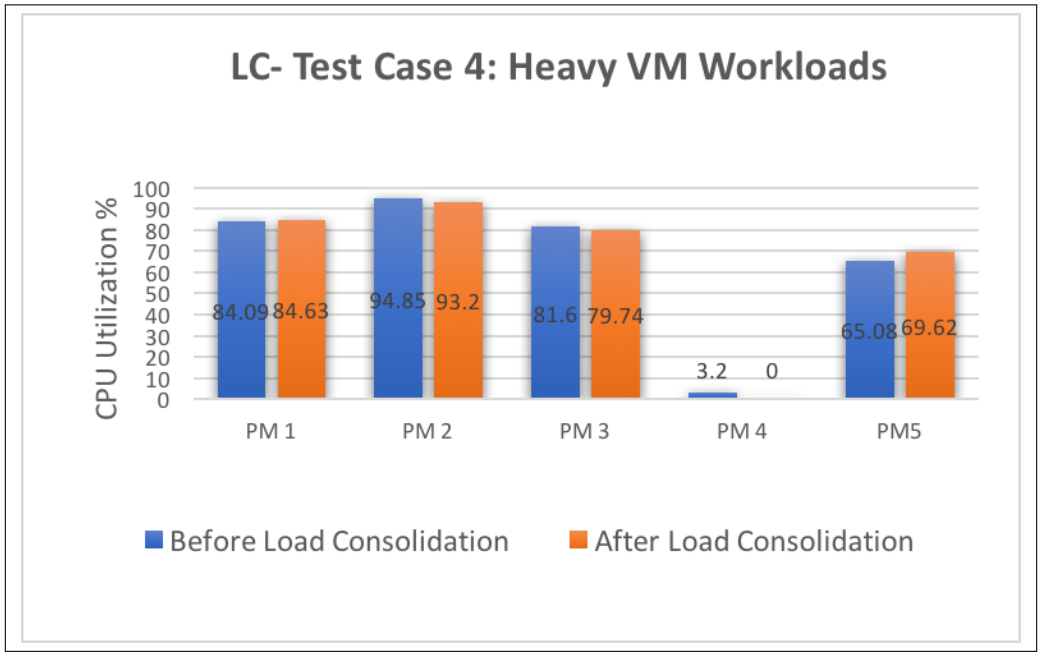


Figure 6.11: LC - Test Case 4: Heavy VM Workload

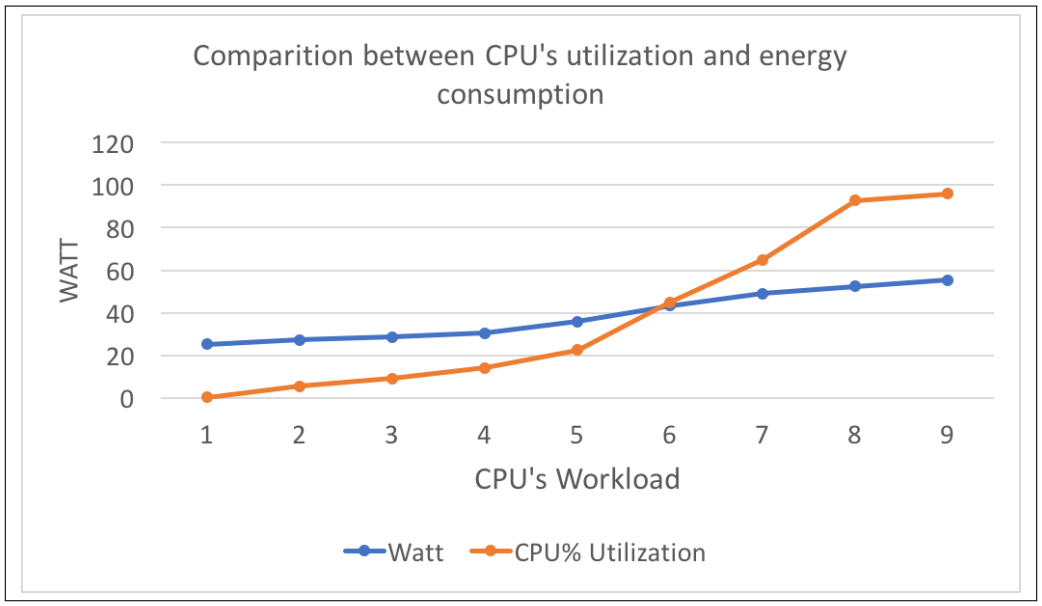


Figure 6.12: The comparison between CPU utilization and Energy Consumption

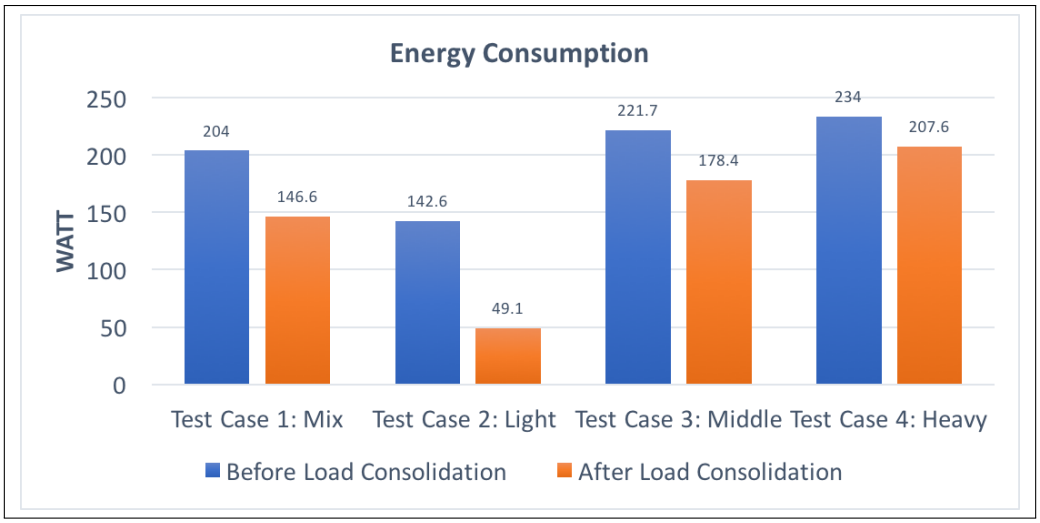


Figure 6.13: Energy Saving after applying Load Consolidation

Chapter 7

FUTURE WORK

In this study we mention two features used by cloud data centers which is load balancing and load consolidation to reach the green cloud. In the load balancing chapter, we provide an algorithm which uses a threshold like a standard to balance CPU's utilization of all compute nodes in a cloud cluster. This approach entirely depended on live VM migration to implement. Live VM migration although is a useful technique to improve the server's performance but it's also an expensive task and consumes the network bandwidth. The new challenge for load balancing is to minimize the amount of live VM migration. From [Farahnakian et al., 2014] Fahimed and et at. mentioned the downtime issue in live VM migration. Because of the fluctuation of the operating system, there is no way to drop downtime unless we don't implement live VM migration. To overcome these drawbacks they provide an approach which determines the extra workload in a VM then migrates to another VM. Relating from their work, in the future work, we will focus on migrating the extra workload of a VM to other VMs in the same host before moving the entire VM to another host.

In the load consolidation chapter, we consolidated VM in the system based on the CPU utilization percentage. However, when moving the VM from a server to another, there are some issues needed to be pointed out such as space of RAM, the conflict between two physical machines, etc. In the future work, we want to build a model which supports to

make a full consolidation plan. This model consists of functions which can compare the different capacity between two or more servers. Furthermore, it's necessary to predict the future workload before making a consolidation plan.

Chapter 8

CONCLUSION

The overgrowing of cloud computing leads to growing cloud data centers, which consume a considerable amount of energy. This study aims to design two features used by cloud data centers which are not only to gain the utilization of server performance but also strive to reduce the energy consumption. Two features mentioned are load balancing and load consolidation. One is load balancing, a process of redistributing the entire workload among compute nodes of the cloud cluster to make resource utilization and improve the response time. In this study, we introduced a load balancing algorithm to handle three issues. First is how to distribute VM requests from users to every compute node in the cloud cluster. Second is how to optimize the CPU utilization of all compute nodes. The last one is how to handle the extreme scenario. The second feature is load consolidation,a process which migrates VMs on a certain amount of physical compute nodes as much as possible and sets idle compute nodes in power saving state to save the energy. For both features, besides describing the problems and giving the solution, we also support the implementations with particular test cases. The results show that the energy consumption of cloud data centers was reduced significantly without violating the performance of the system.

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Appendices

Appendix A

APPENDIX A: SETTING UP THE ARCHITECTURE

A.1 Preparing Compute Node

The following steps are used to setup the compute node. This assumes that virtual extensions are enabled on the machine.

1. Install Ubuntu 14.04 LTS
2. Setup hardware.
3. Install Python3 using *sudo apt-get install Python3*
4. Check the comparability of CPU using this command: *egrep -c '(vmx | svm) /proc/cpuinfo*
5. Install QEMU, libvirt and KVM following by: *sudo apt-get install qemu-kvm libvirt-bin ubuntu-vm-builder bridge-utils*
6. Verify KVM installation by typing: *kvm-ok*
7. Install Virsh manager: sudo apt-get install virt-manager 8. Install tool to connect to other hypervisor: sudo apt-get install virt-manager ssh-askpass-gnome –no-install-recommends
9. Using virt-manager to create VM, manage VM from other hypervisor.

A.2 Setting Up The Network Files

The following steps are to build the network.

1. Vim into the */etc/network/interfaces* file.
2. Using your network configuration to change the network interface file to look like the file shown below.
3. Restart the network service by a command: *sudo systemctl restart networking*

```
  # The loopback network interface
auto lo
iface lo inet loopback

# The primary network interface
#auto enp2s0
#iface enp2s0 inet dhcp
auto br0
iface br0 inet static
  address 192.168.10.11
  netmask 255.255.255.0
  network 192.168.10.0
  broadcast 192.168.10.255
  gateway 192.168.10.1
  dns-nameservers 192.168.10.1 8.8.8.8
  dns-domain greencloudwku.com
  dns-search greencloudwku.com
  bridge_ports enp2s0
  bridge_stp off
  bridge_fd 0
  bridge_maxwait 0
```

Figure A.1: */etc/network/interfaces* File

A.3 Building the Share-storage Network (using GlusterFS)

To implement this tasks, you should have at least 2 computer.

1. Open file *hosts* from */etc/hosts* by root privileges in the first
2. Below the local host definition, you should add names and IP address of others servers

such as 192.168.11.11 Headnode, etc.
3. Install Glusterfs by following these steps:
i. apt-get update
ii.sudo apt-get install python-software-properties
iii. sudo apt-get install software-properties-common
iv. sudo add-apt-repository ppa:gluster/glusterfs-3.8
v. sudo apt-get update
vi. sudo apt-get install glusterfs-server
vii. Start and check glusterfs:
service glusterd start
service glusterd status
viii. Configure firewall : iptables -I INPUT -p all -s <ip-address> -j ACCEPT
ix. Configure trust pool: from storagenode: gluster peer probe node1, gluster peer probe node2, gluster peer probe node3
x. Check peer status: gluster peer status
xi. Create a brick in all server: mkdir -p /data/brick1/gv0
xii. From single server: - this code depending on your storage architecture.
gluster volume create gv0 replica 2 server1:/data/brick1/gv0 server2:/data/brick1/gv0
gluster volume start gv0
xiii. Mount volume to each compute node: mount -t glusterfs server1:/gv0 /mnt
xiv. Check result: ls -lA /data/brick1/gv0/
xv. After creating network file system. All VM's image should be stored in a brick which all compute node can access. This is the requirement for live migration process.

Appendix B

APPENDIX B: LIVE VIRTUAL MACHINE MIGRATION

There are two way to execute live VM migration: 1. By code: virsh migrate –live guest1-rhel6-64 qemu+ssh://host2.example.com/system 2. By virt-manager. Using migrate feature supported by virt-manager.

Appendix C

APPENDIX C: DYNAMIC LOAD BALANCING

C.1 Setting Up the Head Node

1. To communicate between two machine to get the information, a socket is created to pass data between 2 server. In my project, the Head-node will represent as client. And each compute node represent as a server. There are two codes running by Head-node and Computer-nodes to communicate each other.

C.2 Client

```
#!/usr/bin/env python
import socket
import pickle
import time
def socketClient(HOST,PORT,data,flag):
  #HOST = '192.168.10.15'    # The remote host
  #PORT = 50007              # The same port as used by the server
  s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
  temp = True
  while(temp):
    try:
      s.connect((HOST, PORT))
      temp = False
    except:
      time.sleep(5)
  arr = str(data) + '\t' +str(flag)
  s.sendall(arr)
  fromServer = s.recv(2048)
  s.close()
  print 'Received', fromServer
  return fromServer
```

Figure C.1: *client.py*

C.3 Server

There is a simple code from server side which will wait to receive the request from client

```
#!/usr/bin/env python
import socket
######## Server ###################
def socketServer(HOST,PORT):
  request = 0
  temp =""
  s = socket.socket(socket.AF_INET, socket.SOCK_STREAM) #create a socket
  s.setsockopt(socket.SOL_SOCKET, socket.SO_REUSEADDR, 1)
  s.bind((HOST, PORT))
  s.listen(1) # the maximun connect request.
  conn, addr = s.accept() #accept connection from outside
  print "Connected by", addr
  check = True
  while check :
    fromClient = conn.recv(2048)
    if (fromClient):
      data = fromClient.split('\t')
      # need analysis data and process to get MAC address
      conn.sendall(temp) # send MAC address back to Headnode
      check = False
  conn.close()
```

Figure C.2: *server.py*

C.4 All functions need for load balancing and load consolidation

2. All functions needed to run command line in python, get MAC address, get IP address, etc.

```
#!/usr/bin/env python
import subprocess
import shlex
from Client import socketClient
######## Execute command line ######
def executeCom(command):
  args = shlex.split(command)
  proc = subprocess.Popen(args,stdout=subprocess.PIPE)
  (out,err) = proc.communicate()
  return out,err
######## Get name of every VMs #######
def getNameDomain():
# proc = subprocess.Popen(["virsh list --name"], stdout=subprocess.PIPE, shell=True)
# (out,err) = proc.communicate()
  command = "virsh list --name"
  (out,err) = executeCom(command)
  VMName = filter(None, out.split('\n')) ## remove None values
  return VMName,err
######## Get mac address of every VMs ######
def getMACAddr(VMName):
  command = "virsh domiflist "+VMName
  (out,err) = executeCom(command)
  macAddr = out.split(" ")
  return macAddr[-1].strip('\n')
####### Get IP address of every VMs are running ######
def getIP(macAddr):
  arp = subprocess.Popen(('arp','-an'), stdout=subprocess.PIPE)
  output = subprocess.check_output(('grep',macAddr), stdin=arp.stdout)
  ip = output.split(' ')
  ip[1] = ip[1].strip('(')
  ip[1] = ip[1].strip(')')
  print ip[1]
####### Get free VMs ######
def getFreeVMs():
  command = "virsh list --inactive --name"
  (out,err) = executeCom(command)
  freeVMs = filter(None,out.split('\n'))
  return freeVMs
####### Compare vCPU to the real CPU
def compare_vCPU_to_Host(list_CPU_usage):
    # list_CPU_usage includes: [PM1(name of Host, CPU's usage of PM1, number of VMs, CPU's usage
        ↪of VM1,VM2,VM3...),
    # PM2(VM1,VM2,VM3...), ...].
    # Example: list_CPU_usage[0] = [1, 58.15, 5, 10, 30, 40, 60, 80]
    # compare CPU's usage of each VM to its host
    l_CPU_Compare = list_CPU_usage  # list CPU's usage after comparing CPU's usage of every VMs
        ↪to its host
    # Example: ls_CPU_Compare = [PM1[1, 58.15, 5, 2.61, 7.9, 10.52, 15.85, 21.14]]
    for i in range(0, len(list_CPU_usage), 1):
        sum_of_vCPU_Usage = sum(list_CPU_usage[i]) - list_CPU_usage[i][1] - list_CPU_usage[i][2]
            ↪- list_CPU_usage[i][0]
        for j in range(0, int(list_CPU_usage[i][2]), 1):
            # Calculate vCPU's usage compare to its host: 10 * 58.15 / 220(sum)
            tempNum = list_CPU_usage[i][3 + j] * list_CPU_usage[i][1] / sum_of_vCPU_Usage
            tempRound = round(tempNum, 3)
            # for some reason the format of elememt change? Should fix later
            l_CPU_Compare[i][j + 3] = tempRound
            # print l_CPU_Compare
    return l_CPU_Compare
def sendRequests(IP, numberOfVM, flag, port):
    data = socketClient(IP, port, str(numberOfVM), str(flag))
    listMACAddr = data.split('\t')
    listMACAddr.remove('')
    return listMACAddr
```

Figure C.3: *allFunc.py*

C.5 Distributed Workload

3. Code to implement distributed workload.

C.6 Optimize the CPU's utilization

4. When existing VM requests from user to cloud cluster, the head node will process this request to distribute equally to every running PM. This code below represent the distributed workload.

```python
#!/usr/bin/env python
from connectMySql import *
from allFuncs import *
def readPMsList():
    file = open('../data/PMsList.dat')
    lst = []
    i = 0
    for line in file:
        lst += [line.split()]
        # skip the first line by using try and except. The first line is just about introduction such as id,name, ip etc.
        try:
            lst[i][4] = int(lst[i][4])
            lst[i][5] = int(lst[i][5])
            lst[i][6] = int(lst[i][6])
            lst[i][7] = int(lst[i][7])
        except:
            i += 1
            continue
        i += 1
    lst.remove(lst[0])
    return lst  # Id, name, MACAddr, IPAddr, status, VMsOn, VMsOff, MaxVMs
def sendRequests(IP, numberOfVM, flag, port):
    data = socketClient(IP, port, str(numberOfVM), str(flag))
    listMACAddr = data.split('\t')
    listMACAddr.remove('')
    return listMACAddr
# calculate the total number of VMs for each PM
def distributedRequests(listPMs, request):
    distributedList = []
    lackVMs = 0
    tempRe = int(request) / len(listPMs)
    lackVMs = request - tempRe * len(listPMs)
    for i in range(0, len(listPMs)):
        freeVMs = listPMs[i][7] - listPMs[i][5]  # listPMs[i][7] is the maximun VMs that PMs can hold. listPMs[i][5] is the total VMs which are running.
        if (freeVMs >= tempRe):
            distributedList.append([listPMs[i][3], tempRe])
        else:
            lackVMs += tempRe - freeVMs
            distributedList.append([listPMs[i][3], freeVMs])
            listPMs.remove(listPMs[i])
    if (lackVMs >= len(listPMs)):
        newDistributedList = distributedRequests(listPMs, lackVMs)
        for i in range(0, len(newDistributedList)):
            for j in range(0, len(distributedList)):
                if (distributedList[j][0] == newDistributedList[i]):
                    distributedList[j][1] += newDistributedList[i][1]
    else:
        for i in range(0, lackVMs):
            distributedList[i][1] += 1
    return distributedList
# update database
def updateVMTable(PM, listMACAddr):
    fields = ["name", "host", "status", "MAC"]
    check = []
    for vm in listMACAddr:
        vm = vm.split(" ")  # format of vm before split is: "vmName MACAddr"
        values = [("\"" + vm[0] + "\""), ("\"" + PM + "\""), ("\"0\""), ("\"" + vm[1] + "\"")]
        check.append(insertDatabase("VM", fields, values))  # tableName,feilds,values
    return check
```

Figure C.4: *distributeWorkload.py*

```
def main():
    ### Request number of VMs need when running this script ###
    if (len(sys.argv) != 2):
        print("You should add number of VMs request when runs this script!!!")
        exit(0)
    numberVMRequest = sys.argv[1]
    ##############################
    ### Read PMs list ###
    # Need list of IP address of all PMs
    PMsList = readPMsList()
    # print PMsList
    ##############################
    ### Distribute VMs request
    try:
        numberVMRequest = int(numberVMRequest)
    except:
        print ("Number of request should be an integer...")
        exit(0)
    distributedList = distributedRequests(PMsList, numberVMRequest)
    print "Distributed list: ", distributedList
    ##############################
    # The head node sends a request to
    thread1 = sendRequests(distributedList[0][0], distributedList[0][1], 1, 22222)  # IP, request
        ↪ number, flag, port
    ### Update Database and log file ###
    # The idea is to make all VMs ready to use. All status of VMs are 0 that means all VMs are
        ↪turning off and wait from user. When user send one more request to cluster, the VMs will
        ↪ be automatically turned on and return IP address, username and password to user to make
        ↪ the connection
    updateVMTable("node1", thread1)
if __name__ == '__main__':
    main()
```

Figure C.5: *(continue) distributeWorkload.py*

```python
import numpy as np
from allFuncs import compare_vCPU_to_Host
# 0 - sort all CPU's usage from low to high
# 1 - compare loadNeed of heavylyLoadPMs(hList) with freeSpace of lightlyLoadPMs (lList) follows by ordering.
#   Ex: Migrate PM1 belonged to hList to PM2 belonged to lList. It needs migrate 30% to reach threshold -> compare 30% to freeSpace
#     if neededLoad < freeSpace -> loaded need to migrate = needLoad
#     else : loaded need = freeSpace. The remaining will be migrated to the others PM belonged to lList
# 2 - Choose which VMs to migrate:
#   - Take loaded need - the CPU's usage of VMs consumed the most.
#   - If loaded need < max CPU's usage -> skip that VMs and scan the next one.
#   - If loaded need > max CPU's usage -> add this VMs to migrate list.
#         Take the remaining subtract to the CPU's usage of next VMs.
#       The process stops until loaded need ~ (-5% or 5%)
def choosingVM(pm, loadMigrate):
    listVM = []  # need a new list of VM to sort and label the position of VMs to recall it later. Ex: listVM[1] = (VM1,CPU's usage)
    numberVMs = int(pm[2])
    for i in range(1, numberVMs + 1, 1):  # pm[2] is number of VMs in that PM
        listVM.append([i, pm[2 + i]])  # index of VMs starts from 1
    listVM = sorted(listVM, key=lambda x: x[1])  # sort
    listMigrate = []  # VM's
    loadRemain = loadMigrate
    for i in range(len(listVM) - 1, -1, -1):
        if (int(listVM[i][1]) > int(
                    loadRemain + 10)):  # add 5 to loadMirage because we allow to accept the total migrate load between (need - 5% % and need + 5%)
            continue
        if (int(listVM[i][1]) < int(loadRemain + 10)):
            listMigrate.append(listVM[i][0])  # add VM name to listMigrate
            loadRemain = loadRemain - listVM[i][1]
        if ((loadRemain) < (listVM[0][
                                1] - 10)):  # check if the loadRemain less than the smallest CPU load of VM in the list => it means there are no VM can be migrate to reach the threshold
            i = 0
            loadRemain = 0
    return listMigrate, loadRemain
def dynamic_Load_Balancing(l_CPU_Compare):
    # Step 1: Calculate threshold: (CPU_PM1 + CPU_PM2 +..)/number_of_host
    sum_PM_CPU = 0
    numberPM = len(l_CPU_Compare)
    for pm in l_CPU_Compare:
        sum_PM_CPU = sum_PM_CPU + pm[1]
    threshold = round((sum_PM_CPU / len(l_CPU_Compare)), 3)
    mean = round(((l_CPU_Compare[-1][1] + l_CPU_Compare[0][1]) / 2), 3)
    diff = abs(threshold - mean)
    if diff > 10:
        lightThreshold = threshold - diff
        heavyThreshold = threshold + diff
    else:
        lightThreshold = threshold - 10
        heavyThreshold = threshold + 10
    # Step 2: Assign PMs to 3 bands
    lightlyLoadedArr = []  # Store PM[...]
    moderatelyLoadArr = []  # Store PM[...]
    heavilyLoadArr = []  # Store PM[...]
    for pm in l_CPU_Compare:
        if pm[1] < lightThreshold:
            lightlyLoadedArr.append(pm)
        elif pm[1] > heavyThreshold: heavilyLoadArr.append(pm)
        else: moderatelyLoadArr.append(pm)
```

Figure C.6: *CPUOtimization.py*

```
    # Step 3: Check balance
    if len(moderatelyLoadArr) == numberPM:
        return 0  # it means that the CPU's usage of all PMs are nearly equal
    elif len(heavilyLoadArr) == 0 or len(lightlyLoadedArr) == 0:
        return -1  # it means that the system don't need to migrate
    else:
        # It needs to migrate VM
        # Calculate free space to know how many VMs lightly load PM can handle from heavily
            ↪loaded PMs
        lLoadedPM = []  # Ex: lLoadedPM[0] = [PM, free ]
        totalFree = 0
        for pm in lightlyLoadedArr:
            totalFree = totalFree + threshold - pm[1]
            lLoadedPM.append([pm, (threshold - pm[1])])
        # Locate which VMs from heavily loaded PMs to migrate to lightly loaded PMs
        hLoadedPM = []  # Ex: hLoadedPM[0] = [PM, need ]
        totalNeed = 0
        for pm in heavilyLoadArr:
            totalNeed = totalNeed + abs(threshold - pm[1])
            hLoadedPM.append([pm, abs(threshold - pm[1])])
            # Distribute VMs from heavily loaded to lightly loaded
            listMigrate = []
            listVMMigrate = []  # contain list of VMs need to migrate from which hLoadedVM to
                ↪lLoadedVM
        for hPM in hLoadedPM:
            need = hPM[1]
            listVMMigrate = listVMMigrate + [hPM[0][0]]  # add name of heavily loaded VMs
            for i in range(0, len(lLoadedPM), 1):
                if (need == 0):
                    break  # stop the loop when this PM don't need to migrate its work load
                if (need > lLoadedPM[i][1]):
                    loadMigrate = lLoadedPM[i][1]
                    tempList, needRemain = choosingVM(hPM[0], loadMigrate)
                    listVMMigrate = listVMMigrate + [tempList, lLoadedPM[i][0][0]]
                    for j in range(0, len(tempList), 1):
                        a = 2 + int(tempList[j])
                        hPM[0].pop(a)
                        hPM[0][2] = hPM[0][2] - 1  # update number of VMs
                    lLoadedPM[i][1] = 0
                    totalNeed = totalNeed - loadMigrate + needRemain
                    totalFree = totalFree - lLoadedPM[i][1]
                else:
                    loadMigrate = need
                    tempList, needRemain = choosingVM(hPM[0], loadMigrate)
                    listVMMigrate = listVMMigrate + [tempList, lLoadedPM[i][0][0]]
                    freeRemain = lLoadedPM[i][1] - need
                    lLoadedPM[i][1] = freeRemain  # update free space to this light PM
                    totalNeed = totalNeed - loadMigrate
                    totalFree = totalFree - loadMigrate
                    listMigrate.append([int(hPM[0][0]), listVMMigrate, int(lLoadedPM[i][0][0])])
                    if (needRemain <= 0):
                        break
                listVMMigrate = listVMMigrate + ["Next"]
            listVMMigrate = listVMMigrate + ["And"]
    print threshold, mean, diff
    print "List VM from heavy loaded PM need to migrate:"
    print listVMMigrate  # include [name of original PM, list VMs , name of destinational PM]
def main():
    pm1 = [1, 37.25, 3, 40, 60, 50] # Test cases
    pm2 = [2, 4.01, 2, 10, 5]
    pm3 = [3, 44.57, 3, 60, 60, 60]
    cpu_usage = np.array([pm1, pm2, pm3])  # use numpy array to represent array better
    l_CPU_Compare = compare_vCPU_to_Host(cpu_usage)
    a = sorted(l_CPU_Compare, key=lambda x: x[1])  # sorted PMs by CPU's usage
    print l_CPU_Compare
    dynamic_Load_Balancing(a)
main()
```

Figure C.7: *(continue) CPUOtimization.py*

Appendix D

APPENDIX D: LOAD CONSOLIDATION

D.1 Load Consolidation

The algorithm we applied in this study is First Fit Decreasing.

```python
#!/usr/bin/env python
import numpy as np
from allFuncs import compare_vCPU_to_Host
# Label name of host to all VMs before making migration plan
def labelAllVMs(listComparePMs):
    numberPMs = len(listComparePMs)
    listLabelVMs = []  # [ [name of host, index of that VM in list, vCPU]; [] ]
    for i in range(0, numberPMs, 1):
        for j in range(0, listComparePMs[i][2], 1):
            listLabelVMs.append([listComparePMs[i][0], (3 + j), listComparePMs[i][(3 + j)]])
    return listLabelVMs
# Choose PMs to migrate, Applying First Fit Decreasing - Time complexity = O(nlogn)
def firstFit(listLabelVMs, numberOfPM, max):
    numberConsolidatePM = 0
    numberVMs = len(listLabelVMs)
    # generate new PM array with each PM has a limit CPU's usage: 85
    storagePack = []  # create a store including listVMs and space. Ex: [[[PM1,VM1],[PM2,VM2
        ↪]],40]
    # The order of all elements in storagePack is the order of PMs passed to this function.
    for sP in range(0, numberOfPM, 1):
        item = [[], max]
        storagePack.append(item)  # set maximum CPU's usage of each PMs after consolidating.
    for i in range(0, numberVMs, 1):
        # find the first PM which can accommodate weight[i]
        j = 0
        while j < numberConsolidatePM:
            if (storagePack[j][1] >= listLabelVMs[i][2]):
                storagePack[j][1] = storagePack[j][1] - listLabelVMs[i][2]
                storagePack[j][0].append([listLabelVMs[i][0], listLabelVMs[i][1]])  # add label
                    ↪and index of that VMs
                break
            j += 1
        if j == numberConsolidatePM:
            storagePack[j][1] = max - listLabelVMs[i][2]
            numberConsolidatePM += 1
            storagePack[j][0].append([listLabelVMs[i][0], listLabelVMs[i][1]])
    return storagePack  # [ [name of host, index of that VM in list, vCPU]; [] ]
# Design the consolidation plan
def firstFitDecresing(l_CPU_Compare, numberOfPM, max):
    # Step1: Lable all VMs with its host before merge all VMs together
    # ListLabelVMs include (name of host, index of that VMs in list, vCPU
    listLabelVMs = labelAllVMs(l_CPU_Compare)
    # Step2: Sort all vCPU follow decreasing order.
    listSortedLabelVMs = sorted(listLabelVMs, key=lambda x: x[2], reverse=True)
    # Step3: Call firstFit function
    listPMCadidate = firstFit(listSortedLabelVMs, numberOfPM, max)
    return listPMCadidate  # return all posible PMs which parts or entire can be moved to other
        ↪PMs
def main():
    pm1 = [1, 58.15, 5, 10, 30, 40, 60, 80]  # (name of Host, CPU's host, number of VMs, vCPU
        ↪...)
    pm2 = [2, 65.08, 3, 90, 90, 80]
    pm3 = [3, 37.25, 3, 40, 60, 50]
    pm4 = [4, 44.57, 3, 60, 60,60]
    pm5 = [5, 46.6, 3, 60, 60, 60]
    cpu_usage = np.array([pm1, pm2, pm3, pm4, pm5])  # use numpy array to represent array better
    l_CPU_Compare = compare_vCPU_to_Host(cpu_usage)
    lPM = []
    for pm in l_CPU_Compare:
        if pm[1] < 85:
            lPM.append(pm)
    numberOfPM = len(lPM)
    print firstFitDecresing(lPM, numberOfPM, 85)
if __name__ == '__main__':
    main()
```

Figure D.1: *loadConsolidation.py*