CHIMA DESMOND OPARA CLOUD COMPUTING IN AMAZON WEB SERVICES, MICROSOFT WINDOW AZURE, GOOGLE APP ENGINE AND IBM CLOUD PLATFORMS: A COMPARATIVE STUDY NEU 2019

CLOUD COMPUTING IN AMAZON WEB SERVICES, MICROSOFT WINDOWS AZURE, GOOGLE APP ENGINE AND IBM CLOUD PLATFORMS: A COMPARATIVE STUDY

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
CHIMA DESMOND OPARA

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Computer Information Systems

NICOSIA, 2019

CLOUD COMPUTING IN AMAZON WEB SERVICES, MICROSOFT WINDOWS AZURE, GOOGLE APP ENGINE AND IBM CLOUD PLATFORMS: A COMPARATIVE STUDY

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
CHIMA DESMOND OPARA

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Computer Information System

NICOSIA, 2019

Chima Desmond OPARA: CLOUD COMPUTING IN AMAZON WEB SERVICES, MICROSOFT WINDOWS AZURE, GOOGLE APP ENGINE, AND IBM CLOUD PLATFORMS: A COMPARATIVE STUDY

Approval of Director of Graduate School of Applied Sciences

Prof. Dr. Nadire CAVUS

We certify this thesis is satisfactory for the award of the Degree of Masters of Science in Computer Information Systems

Examining Committee in Charge:

Assoc.Prof.Dr. Fezile Özdamlı	Committee Chairperson, Department of Computer Information Systems, NEU
Prof.Dr. Nadire Çavuş	Supervisor, Department of Computer Information Systems, NEU
Asst.Prof.Dr. Damla Karagözlü	Co-Supervisor, Department of Computer Information Systems, NEU
Assoc.Prof.Dr. Hüseyin Bicen	Department of Computer Education and Instructional Technologies, NEU
Asst.Prof.Dr. Sezer Kanbul	Department of Computer Education and Instructional Technologies, NEU

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Chima Desmond Opara

Signature:

Date:

To my amazing family…

ACKNOWLEDGEMENT

First of all, I would like to express my deepest appreciation to my supervisor Prof.Dr. Nadire Cavus, and co-supervisor Assist. Prof.Dr. Damla Karazoglu for their overall guidance and patience throughout my research. The preparation of this Thesis would never have been possible without their constructive suggestions, continual encouragement, and assistance.

I would also like to thank all my lecturers in Computer Information Systems department, who have all made my studies here a success.

My profound gratitude goes to my parents Mr and Mrs Opara, for your love, sacrifice, and support. Thank you very much for everything you have done for me in life. To my brother Nonso and sisters Otito, Amarachi and Loretta, you mean the world to me. Thank you for being there for me and encouraging always.

I am also thankful to all my friends, course mates, and well-wishers who have contributed during this Thesis directly or indirectly. I appreciate you all.

ABSTRACT

Cloud computing is a rapidly growing field in the Information technology sector. Recently there are many emerging cloud platforms to choose from to run, deploy and maintain applications over the cloud, offering a variety of services and tools at the disposal of a user. Cloud users are faced with the dilemma of selecting a suitable platform that meets their specifications. The aim of this study is to compare four widely adopted cloud platforms, AWS, Microsoft windows azure, Google app engine and IBM cloud based on some commonly shared features such as cloud service type, storage, database, security, service level agreements, programming languages used, pricing, virtualization, mobile services offered, internet of things, data backup and recovery and user interface to guide customers in selecting a suitable cloud platform. The result of the comparison suggested that AWS fits the needs of large companies due to their vast global reach, Microsoft windows azure is suitable for startups and best fits organizations using Window servers, Google app engine is the most cost-efficient and suitable for developers of web based software and applications, IBM cloud appealed to users because of its unique virtualization and private cloud services. This study is beneficial for potential users such as small mid-size enterprises, start-up developers and large companies for selecting a cloud platform that meets their requirements.

Keywords: Cloud computing; cloud platforms; comparison; AWS; Microsoft window azure; Google app engine; IBM cloud

ÖZET

Bulut bilişim, Bilgi teknolojileri sektöründe hızla büyüyen bir alandır. Son zamanlarda, bulut üzerinden uygulamaları çalıştırmak, dağıtmak ve bakımını yapmak için aralarından seçim yapabileceğiniz ve kullanıcının emrine çeşitli hizmetler ve araçlar sunan birçok yeni bulut platformu bulunmaktadır. Bu çalışmanın amacı; bulut hizmet türü, depolama, veritabanı, güvenlik, hizmet düzeyi sözleşmeleri, programlama dilleri, fiyatlandırma, sanallaştırma, sunulan mobil hizmetler, internet işleri, veri yedekleme kurtarma ve kullanıcı arayüzü uygun bir bulut platformu seçiminde müşterilerine rehberlik etmek gibi yaygın olarak paylaşılan bazı özelliklere dayanarak yaygın olarak kabul edilen dört bulut platformunu, AWS, Microsoft windows masmavi, Google uygulama motoru ve IBM bulutunu karşılaştırmaktır. Karşılaştırmanın sonucu, AWS'nin geniş küresel erişimleri nedeniyle büyük şirketlerin ihtiyaçlarına uyduğunu, Microsoft Windows Azure'un yeni başlayanlar ve Windows sunucularını kullanan kuruluşlar için en uygun olduğunu, Google uygulama motorunun web tabanlı yazılım ve uygulama geliştiricileri için en uygun maliyetli ve uygun olduğunu, IBM bulutun benzersiz sanallaştırma ve özel bulut hizmetleri nedeniyle kullanıcılara hitap ettiğini ortaya koymuştur. Bu çalışma; küçük orta ölçekli işletmeler, başlangıç geliştiriciler ve büyük şirketler gibi potansiyel kullanıcılar için gereksinimlerini karşılayan bir bulut platformu seçmeleri açısından faydalıdır.

Anahtar Kelimeler: Bulut bilişim; bulut platformları; karşılaştırma; AWS; Microsoft windows masmavi; Google Uygulama Motoru; IBM bulut

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AMI: Amazon Machine Image

APRANET: Advanced Research Projects Agency Network

AWS: Amazon Web Services

EC2: Elastic Compute Cloud

GAE: Google App Engine

HPC: High Performance Computings

IAAS: Infrastructure as a service

MWA: Microsoft Windows Azure

NIST: National Institute of Standards and Technologies

PAAS: Platform as a Service

SAAS: Software as a service

SLA: Service Level Agreement

SQS: Simple Queque Service

S3: Simple Storage Service

VM: Virtual Machine

VPN: Virtual Private Network

WAN: Wide Area Network

YOY: Year over Year

CHAPTER 1

INTRODUCTION

This chapter focuses on the background of the study, problem statement for this study, the aim of the study, the significance of the study, the limitation of the study and the overview of all the chapters in this Thesis.

1.1. Background of the Study

Cloud Computing has become a fast growing IT architecture paradigm. Most companies, small and mid-size enterprises as well as individuals can adopt a cloud computing platform to store a large number of data which is easily accessible via the internet from any location (Purohit, 2017; Dordevic et al., 2014; Deshmukh and Mishra, 2018).

Many major stakeholders in the IT sector have invested big in cloud computing technologies by creating their public servers, including Google, Microsoft and Amazon. Such businesses intermittently release fresh characteristics and versions of their cloud services (Hofer and Karagiannis, 2011).

Cloud service variety contributes to a feasible issue. How well does a cloud service function compared to other services? Responding to the above issue will profit both cloud clients and vendors. This response may assist a potential user pick the right cloud platform which fits their performance and price requirements. For example, one platform can be selected for memory-intensive apps and another for computing-intensive apps. Responses like this may lead to the desired path for development for a cloud service provider, notwithstanding the real significance of comparing cloud service providers, several research were carried out over this subject. The dilemma is that each provider has its own peculiar methods of doing stuff, so figuring a commonality requires a lot of thinking (Li et al., 2010).

Nowadays, businesses and individuals intending to use cloud platforms are faced with a wide range of potential cloud options. Due to the vast number of alternatives, it is difficult to guide themselves and find a better option. Cloud solutions deliver the best possible service to their clients. The advantages of these services must be evaluated based on the suitable needs of a client (Giovanoli, 2019).

In this Thesis study, four popular adopted cloud platform namely Amazon web services, Microsoft windows azure, Google app engine and IBM cloud compared based on the following considered features: Cloud service type, storage, database, security, service level agreements (SLA), programming languages used, pricing, virtualization, mobile, internet of things, data backup and recovery and user interface for the comparison of cloud platforms, guide a potential user in selection and give suggestions of where each platforms fits better.

1.2.Thesis Problem

There are numerous cloud platforms with varying storage capabilities, attributes, mechanism and pricing methods. The major issue faced recently, is that potential users do not know which cloud platform meets their specification, therefore selecting the suitable cloud platforms becomes a dilemma for them (Deshmukh and Mishra, 2018). With the vast number of cloud platforms readily accessible to those parties keen on it, there might be different criteria for choosing a specific cloud platform. Those criteria rely on a variety of logics in terms of efficiency, the capacity of a company, expenditure, security and storage requirements (Purohit, 2017). Therefore it is paramount not to only know the advantages and disadvantages of cloud platforms and the criteria for choosing a cloud platform but to also compare the four widely adopted cloud platforms based on some common features with similarities and differences to guide business enterprises, companies and individuals choose of the suitable platform for startups, hybrid solutions, large organizations and cost effective cloud platforms for potential users.

1.3.Aim of the Study

The aim of this study is to compare four popular cloud platforms namely Amazon web services, Microsoft window azure, Google app engine, and IBM clouds based on twelve selected features to help small and medium sized enterprises or businesses and potential users make a choice of cloud platforms to adopt.

1.4. Significance of the Study

The significance of this study is to guide business enterprise, companies and individual choice of suitable cloud platform selection based on some common features that satisfies potential users need in terms of cost efficiency and performance as well as possibly assisting a provider to recognize its underperforming services compared to other strong competition.

1.5. Limitations of the Study

All the data used for the research are secondary and as such will be restricted to previous studies, high prestige journals. This study is limited to the four chosen platforms and the twelve selected features for the comparison.

1.6. Overview of the Thesis

This thesis consists of six chapters, which are Introduction, Related research, Theoretical framework, Methodology, Results and Discussions, and Conclusions and Recommendations

Chapter 1 is an introductory chapter of the whole thesis work, outlining the thesis problem, aim of the study, significance of the research and the limitations of the study.

Chapter 2 is a literature review of previous studies carried out and related to the present research.

Chapter 3 is the theoretical framework detailing cloud computing overview, including the currently available cloud computing services architecture and cloud computing platforms.

Chapter 4 outlines the method used for the comparative analysis of the cloud computing platforms as well as the main features of cloud services used for comparative analysis.

Chapter 5 presents the results and discusses the comparison to other studies missing gap

Chapter 6 draws a conclusion on the study as well as makes recommendation for interested future researchers of cloud computing platforms comparison.

CHAPTER 2

RELATED RESEARCH

This chapter looks at the related research on cloud computing platforms comparison involving Amazon web services, Microsoft windows azure, Google app engine and IBM clouds conducted by various authors, the findings from their study are summarized and the missing gap which could be pointed out.

2.1 Comparative Studies

BV et al. (2013) compared two leading cloud platforms AWS and Microsoft azure. They focused their study on three important cloud features, storage, type of cloud and compute service provided. They detailed their comparison in a tabular form with all mentioned features as well as some example of case studies for users and made recommendations. They concluded that Amazon RDS is charged depending on the deployment method which are Standard and multi-AZ while SQL azure is charged by the storage space used. Both AWS and Azure use all three cloud service type.

Bari et al. (2015) carried out a study and compared AWS, Microsoft azure and Rackspace. They focused their comparison on cost and performance of these platforms. They conducted an experiment of small, medium and large computation using memory and CPU for the cost while they calculated the response to time in the experiment for performance using PHP SDK. They result for their analyses concluded that AWS did have the better cost plans for small and medium scale computing, on the other hand Microsoft had an advantage when it came to large scale computing. Rackspace proved costlier across for the three scenarios, as such AWS was found to be more value-effective answer in the present condition.

Purohit (2017) carried out a research to compare and analyze some cloud service providers which included AWS, Microsoft azure, Google IBM clouds, Rackspace, VMware, Red Hat and oracle cloud based on some distinctive features in those platforms such as computing and encryption method, storage, networking and properties, and sales customer support. In his logical analysis, he used a table to illustrate where these cloud platforms are more fitting to be used and giving examples of the users. His analysis concluded by emphasizing on duty of the customer to evaluate these services before selecting a platform satisfactory to them.

Hyseni and Ibrahimi (2017) conducted a research that compared the cloud computing platforms in Amazon and Google based on seven available services provided by both which were computing, storage, database, networking, management tools, development tools and security/identity. Their research concluded according to the compared features that customers should prioritize AWS cloud platform because it has more services available even though Google platform provides a cheaper rate per instance.

Aljamal et al. (2018) carried out a survey on the high performance computing (HPC) of four popular cloud platforms according to them, which were Microsoft azure, Amazon, Google and oracle. They reviewed the services on offer and comparative advantages of each of the selected cloud platforms to help customers of HPC apps. They features used for their study are VM types, batch processing, storage, migration tools, developer tools, management tools, Pricing methodology, policy and discount. Their study concluded that not all cloud platforms might satisfy customers' specification but most of them provide a lot of services and facilities to retain and captivate new and old users. However Amazon and Microsoft prove to be more popular among users due to their prominence.

Deshmukh and Mishra (2018) compared, AWS, Microsoft azure, Google and IBM cloud platforms based on their advantages and disadvantages. Their study was focused on helping customers to choose the best cloud platform that meets their specification. They concluded that most platforms concentrate on offering various services, a few on concentrate on offering services at minimal price and others offering excellent security, confidentiality and integrity of data which are more vital to customers.

Dutta and Dutta (2019) conducted an analyses of top three leading cloud platforms according to them which were AWS, Microsoft and Google. Their analyses focused on what these platforms provided in regards to storage, compute and management tools. In their analyses they concluded that even though AWS has the higher market share, it would be inaccurate to assume it offers the best services, this is because Microsoft and Google platforms certainly have additional benefits for services and better security mechanisms. They gave a recommendation for organizations to use more than one platform to minimize risk.

Laxmaiah and Sharma (2019) analyzed three well known cloud platforms which included Google, AWS and Microsoft azure. They focus of their analyses was to compare these platforms based on the following features, cloud services, platform supported, language supported, integrated DB support and SLA. They concluded from their analyses that each platform has a well-defined features for users. Their paper is going to have an extension of Microsoft azure practical implementation.

2.2 Performance and Service Analysis

Dordevic et al. (2014) conducted a study, comparing two commonly used cloud computing platforms Microsoft azure and Amazon Web services. Their study was focused on the performance and services comparison of both platforms. They carried out a test in the same virtual machine on Ubuntu Linux Server 14.04 LTS 64-bit for micro instances where performance was tested based on the features the researchers chose for the test which are Price per hour, CPU cores, disk space and RAM. Their result concluded that in regards to performance, both platforms are quite comparable, although the result gives a slight edge to Microsoft azure if it were only based on CPU and disk space.

Wahid and Banday (2018) conducted a study, comparing AWS, Microsoft Azure and Google based on the following parameters CPU, memory and Price. Their study was focused on helping customers in India in decision making of cloud platform in regards to cost and performance. They result of their analyses concluded that AWS was the best choice among the mentioned

platforms due to its range of machine type as well as broad available cost plans, thus making it easier for user to choose an option. While Microsoft and Google were fast thriving and providing a range of quality and affordable cost plans, the analyses was in complete favor of AWS.

Kaur et al. (2018) compared AWS and IBM cloud by testing both in similar circumstances, utilizing their various examples. Their study focused in terms of performance and safety measures of these platforms. They compared both platforms based on the safety mechanism used and the cost price for their cases using a Phoronix test suite. Their result concluded that AWS does have a higher level of acceptance than almost all other offered cloud services and it's primarily popular to new customers while IBM is innovating but still has a longer way to get there. AWS also has an exceptional RAM speed than IBM. Finally in security aspect, AWS has a more strict approach while IBM is a little behind in this regards.

Tajadod et al. (2012) investigated and compared main features of Microsoft azure and AWS cloud platform that offer security focused on data integrity, availability and confidentiality. Their result showed that both adopt various security frameworks, Microsoft is assured security via its azure platform framework while Amazon via its Amazon elastic compute framework. Nonetheless, Microsoft's cryptographic cloud storage proved to be a significant distinguishing feature to Amazon due to the level of complexity as well as the reason it ensures a higher rate of data security and privacy. They concluded Microsoft simply offers a higher level of data protection than AWS.

Li et al. (2010) designed a systematic comparator called cloudcmp to assist users in choosing a cloud platform based on the performance and cost price. They selected and compared four popular cloud platforms at the time of their research, which were AWS, Microsoft azure, Google and Rackspace cloud. They focused their study on helping users to easily make a choice of the cloud platform that meets their demands and wants. They main features used for their experiment were elastic compute cluster, persistent storage, intra-cloud network and wide area network. Their result concluded that AWS and Rackspace had the same price range even though AWS was thirty percent costly per hour and instance while Microsoft and Google were provided higher performance but were fifty percent more costly which is due to having fast CPU. They

recommended adding others cloud platforms to the cloudcmp system in the future for user to have a wider selective option.

2.3 Summary of Related Research

Table 2.1 below shows a summary of the related research discussed in this chapter. It shows the authors of the research, the aim of the research, cloud platforms compared, features compared, the comparison type which were classified as quantitative or qualitative, the conclusion and recommendations of their research. This study seeks to widen the gap in understanding in (Purohit, 2017) beyond the features such as computing, networking and storage mechanism of which were compared. The study seeks to widen the gap in Deshmuhk and Mishra, (2018) understanding beyond the advantages and disadvantages of the selected cloud platforms and also widen the gap in Laxamaiah and Sharma, (2019) beyond the features such as cloud services, platform supported, languages supported, Integrated database and SLA.

Table 2:1: Summary of related research

AUTHOR (YEAR)	AIM	CLOUD PLATFORMS COMPARED	FEATURES COMPARED	COMPARISON TYPE	CONCLUSION
Purohit (2017)	To give a detailed description of the features offered by the cloud platforms listed.	AWS Microsoft azure Google IBM cloud Rackspace VMware Red Hat Oracle cloud	Compute, storage, networking,	Quantitative	Emphasized the duty of customers to evaluate these services before selecting a satisfactory platform to them
Hyseni and Ibrahimi (2017)	To compare the cloud computing platforms offered by AWS and Google	AWS Google	Compute, storage, database, networking, management and development tools	Quantitative	Potential customers should prioritize AWS over Google because it has more available services and provides a cheaper rate per instance
Ajamal et al. (2018)	To review the services on offer and comparative advantages of selected platforms to help users of HPC apps.	Microsoft azure AWS Google Oracle	VM types, storage, migration, development, and management tools, pricing, policy & discount	Quantitative	Not all cloud platforms satisfies customers specification, but AWS and Microsoft azure proved popular among customers due to their prominence

Table 2.1: *Continue*

Kaur et al. (2018)	To compare security mechanism and cost prices in place in the mentioned cloud platforms	AWS IBM cloud	Security measures, cost price	Qualitative	AWS proved to have a higher level of security measures, acceptance and primarily popular to new customers than IBM cloud
Wahid and Banday (2018)	To help customers in India with decision making of cloud platforms in regards to cost and performance	AWS Microsoft azure Google	CPU, Memory, Price	Qualitative	AWS was the best choice among mentioned platforms due to the range of machine type and available cost plans
Deshmukh and Mishra (2018)	To help customers choose the best platform that meets their specification	AWS Microsoft azure Google IBM cloud	Advantages and Disadvantages	Qualitative	All cloud platforms have distinct services, up to customer to decide which meets specification
Laxmaiah and Sharma (2019)	To compare these platforms based on the listed features to help users' options.	Google AWS Microsoft azure	Cloud services, Language supported, integrated DB support, SLA	Qualitative	Each platform has a well-defined features to meet users specification

Table 2.1: *Continue*

Dutta and Dutta (2019)	To analyze these platforms provided in regards to the listed features.	AWS Microsoft azure Google	Storage, compute, and management tools	Quantitative	Organizations should use more than one platforms to minimize risk
Bari et al. (2015)	To compare these platforms in regards to the listed features	AWS Microsoft azure Rackspace	Cost, and performance	Qualitative	AWS was found to be more cost effective answer with the present condition
Dordevic et al. (2014)	To compare both platforms in regards to performance and services offered	Microsoft azure AWS	Performance, service and comparison	Qualitative	Microsoft azure has a slight edge based on CPU and disk space
BV et al. (2013)	To compare both platforms in regards to the listed features	AWS Microsoft azure	Storage, compute, and type of cloud	Quantitative	Both provide the three cloud service type
Tajadod et al. (2012)	To compare both platforms security mechanism	Microsoft azure AWS	Security mechanism	Qualitative	Microsoft simply offers higher level of data security than AWS
Li et al. (2010)	To design a comparator to help users choose a cloud platform based on the listed features	AWS Microsoft azure Google Rackspace	Compute, storage, network performance	Quantitative	Microsoft and Google provided higher performance but are more costly than AWS and Rackspace

CHAPTER THREE

THEORITICAL FRAMEWORK

This chapter gives an overview of cloud computing, in terms of definition, history, architectural design, important characteristics, types of delivery model and the four popular platforms chosen for this study are explained.

3.1. New Technological Development in Information Technology Sector

Across the world, technology is changing lives of people and businesses every day with new innovations on the market to ease the way people do things on a daily basis. Several organizations came up with better, quick, and minimal cost innovation to deal with the problems of storing data and reliability concerns to customers which is generally called cloud computing today. In early 2000's, a number of US businesses were already adopting cloud computing to access services on request, however recently this technology has gained attention in other countries. Users store data and access it via the internet and the cloud platform domain the adopted (Chandel et al., 2018).

Cloud computing has completely changed the IT sector owing to its rapid growth and demand. The rapid increase in deployed cloud computing has led to the establishment of large data centres involving a massive variety of sophisticated server (Kaur et al., 2018).

3.2. Cloud Computing

There are plenty definitions of cloud computing by numerous researchers but the generally acknowledged one is from the National Institute of Standards and Technologies (Wahid and Banday, 2018) which defined cloud computing as

> "The framework for enabling simple, on-demand network connection to a separate system of computing resources (For example network servers, storage application, and services) that can be distributed and released rapidly with restricted managerial intervention or client interference" (Mell and Grance, 2011: p. 34).

The essential features which differentiate cloud computing from conventional computing alternatives have been recognized (Wang et al., 2010; Zhang et al., 2010; Hofer and Karagiannis, 2011) typically include:

- Design on scalability and agile facilities.
- Buy on-demand service delivery and level of service incentives.
- Pay for the use of system resources without the upfront loyalty of cloud customers.
- Shared and multi-tenancy.
- Each and every device is accessible over the Internet.

3.2.1. History of Cloud Computing

Cloud computing has gone through a rapid change in history from the 1960's to the present day and possibly in the distant future.

J.C.R Licklider in the late 1960's, the man credited with facilitating the advancement of APRANET, who had a vision to see people globally connected and having access to data via the internet anywhere, came up with the concept of Intergalactic computer Network which is equivalent to the internet today (Narula et al.,2015).

Later in 1970, virtualization was launched, running of multiple operating system concurrently in a confined setting with software such as VMware, thus the birth of virtual machines. By 1990, telecoms companies began offering VPN connections providing users with shared connectivity to existing infrastructure (Neto, 2019).

Professor Ramnath Chellapa in Dallas, USA in 1997, computing as "A computing model in which the limitation of computing will be determined by economic logic instead of technical limits only"(Agarwal et al., 2016).

Amazon became the pioneer of cloud computing in the early 2000's , providing services through Elastic compute cloud and simple storage service, as well as introducing the pay as use model to individuals and companies at large. Google became a strong rival in the sector of ecommerce

in late 2000's, by 2006, Google released its first cloud-based service called Google Docs, which allows a user to save and share documents precisely with various users (Agarwal et al., 2016).

3.2.2 Cloud Computing Architecture

The National Institute of Standards and Technology (NIST) is a well prominent organization worldwide because of its research in the area of IT. In figure 1, NIST illustrated the five important characteristics, the three services and four ways clouds are deployed in the architectural design of cloud computing (Sharma et al., 2016).

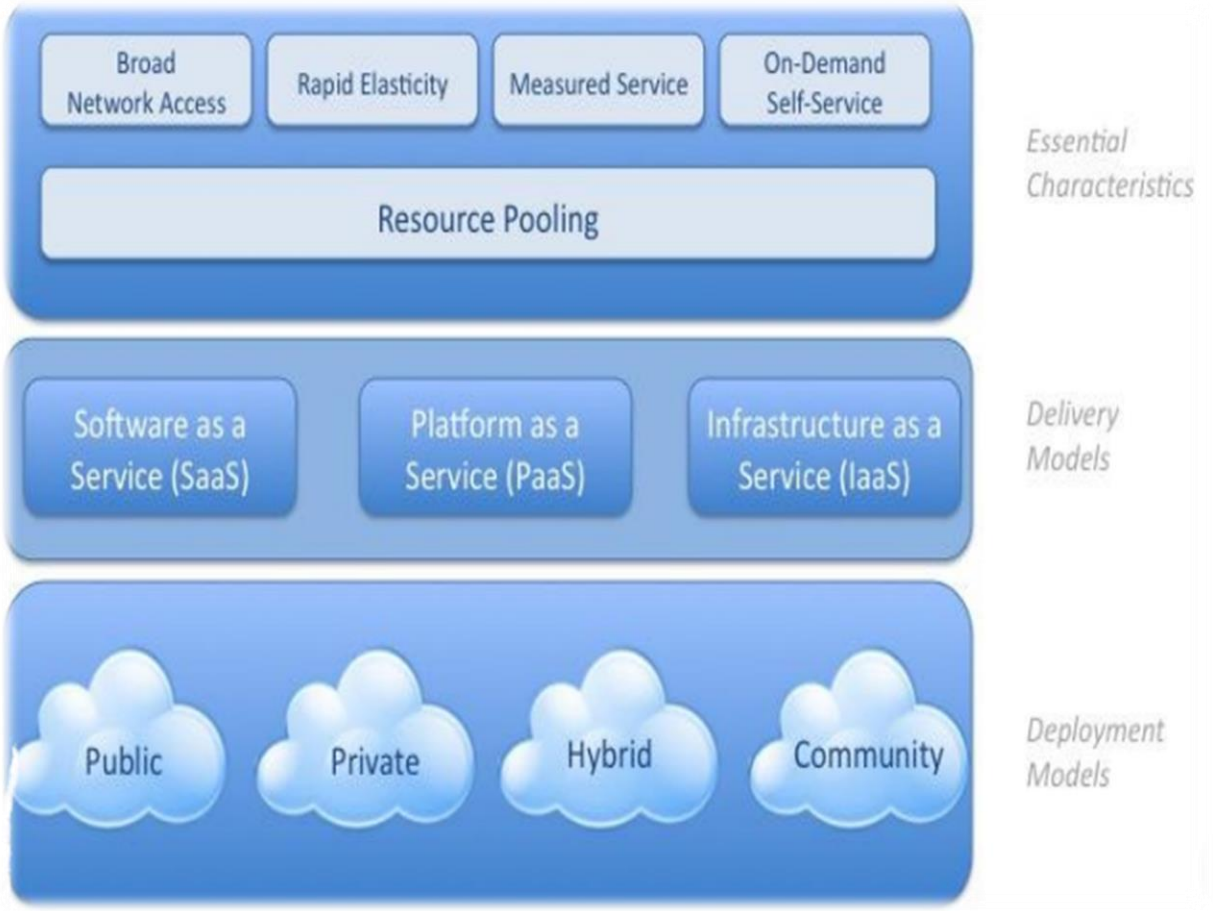


Figure 3.1: Architectural design of cloud computing (Sharma et al., 2016)

There are five very important characteristics of cloud computing as shown in Figure 3.2 which clearly points out the relationship as well as contrast against the conventional computing.

- ***Broad Network Access:*** It has network-wide capacities and connect directly by normal system (Kapil et al., 2017).
- ***Rapid elasticity:*** Its services are flexible and provided quickly (Alam et al., 2015).
- ***Measured Service:*** The systems in cloud computing manage and enhance the use of resources by offering a capacity measurement to the model of the services such as storage, processing and bandwidth (Alam et al., 2015)
- ***On-demand-self-service:*** Computational services are offered via the internet at a particular moment with no communication depending on the customer's necessity. Users can access information, apps or another resources in cloud services with the assistance of a just a web server, disregarding a software and hardware (Kapil et al., 2017).
- ***Resource Pooling:*** It depends on customer requirements, cloud services assets are collected to serve various customers (Sahu and Pateriya, 2013).

3.2.3 Types of Cloud Computing Delivery Models

Generally, cloud computing is classified into three types namely Software as a service (SaaS), Platform as a service (PaaS) and Infrastructure as a service (IaaS). Figure 3.3, below shows the type of cloud services with some examples and their respective main users (Čandrlić, 2019):

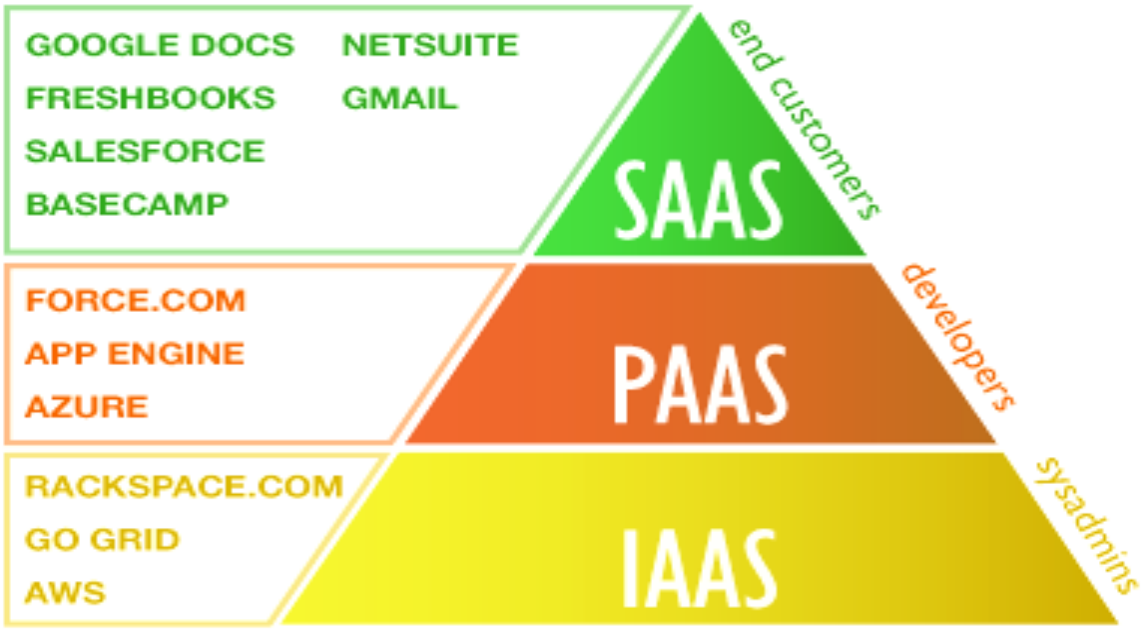


Figure 3.2: The types of cloud computing service with examples (Čandrlić, 2019)

- ***Software as a Service (SaaS):*** Provides services where by users don't have to handle any operating system installation and setup instead it is managed by the cloud service provider (Sahu and Pateriya, 2013). Examples include Customer Relationship Management (CRM), Email, Enterprise Resource Planning (ERP), Games.
- ***Platform as a Service (PaaS):*** This service allows users to develop a software using the cloud platform supported tools and settings. The user also controls the software installation and configuration (Sarma et al., 2019). Examples include Streaming, Decision support, web server, development tools (Al-Sayyed et al., 2019)
- ***Infrastructure as a Service (IaaS):*** This offers company entry to essential internet design, like storage room, servers, and connections, without having to buy and manage this internet-world facilities itself. The major benefit about is that users would only have to pay for the period of time the service is being used by them (Jadeja and Modi, 2012). It can be used to prevent purchasing, housing, and handling fundamental operating

systems service parts, swiftly measure back and forth to satisfy demand. E.g. Amazon EC2 (Sahu and Pateriya, 2013). Examples include Virtual Machine, Network, Servers, Storage, load balancer (Al-Sayyed et al., 2019).

Table 3:1 below shows cloud computing model, services available for each, people who use this model, why the use it and examples of cloud platforms that offer such models

Table 3:1: Cloud computing delivery model (Kimmy, 2013)

MODELS	SERVICES AVAILABLE	USED BY	WHY USE IT	EXAMPLES
SAAS	Email, office automation, website, testing, wiki, virtual, desktop, blog, CRM	Business users	To complete business tasks	Salesforce.com, Animato, Oracle on demand, Windows Office Live
PAAS	Services, applications test, development, integration, and deployment	Developers	Create or deploy applications and services for users	Google App Engine, Microsoft Azure, Coghead, Force.com, Yahoo, Developer Network
IAAS	Create platforms for service and application test. Development, migration and deployment	System manager	Create platform for service and application test, integration, and deployment	Amazon EC2, Simple Storage Service (S3), Go-grid

3.2.4. Advantages and Disadvantages of Cloud Computing

With the rapid growth of cloud computing in the IT sector, many businesses are adopting it, because of its numerous benefits. As with many new technologies, cloud computing has many advantages and a few disadvantages.

Xue and Xin, (2016) explained how cloud computing enables businesses to be more flexible by accessing data via internet from any location at any given time, offers reduced cost on pay as you use basics, scalability is simple with the help of virtualization and boosts agility by providing infrastructure, backup and recovery, and software management to businesses or organizations adopting it.

Kapil et al. (2017) highlighted a vital functional disadvantage of cloud computing which happens to be the shortage of integration among cloud platforms. This has happened primarily because companies have designed their clouds and kept the design, layout, and system private, although several cloud platforms advertise 99 percent or higher service accessibility of their product quality, most apps are not properly equipped for the utilization of the cloud.

3.3. Most Popular Cloud Computing Platforms

There are many cloud computing platforms with plenty of advantages. This study considers four popularly adopted platforms namely Amazon web services, Microsoft windows azure, Google app engine and IBM cloud.

3.3.1 Amazon Web services

This is provided by Amazon which was launched in 2006, known today as the pioneer in cloud computing. Amazon web services offers on request cloud services to different kind of users such as firms, organizations, business enterprises. Customers mostly use the pay as you go option for available services which allows them to completely manage the virtual servers with assistance via the web (Swedha and Dubey, 2018).

AWS offers a vast array of cloud services that helps in the improvement of complex apps. It also allows the deployment of applications on a global scale at a minimal cost. The user just pays for the services used on a fixed rate (Ferriman et al., 2015).

Examples of some popular clients of AWS are US Navy, Unilever, Kellogg's, and Siemens (Purohit, 2017).

Figure 3.4 shows the components of AWS which are Monitoring, Management, Tools, Networks, Processing, Content Delivery, Messaging, Payments, On-Demand workforce and the main features which are compute, storage and database available

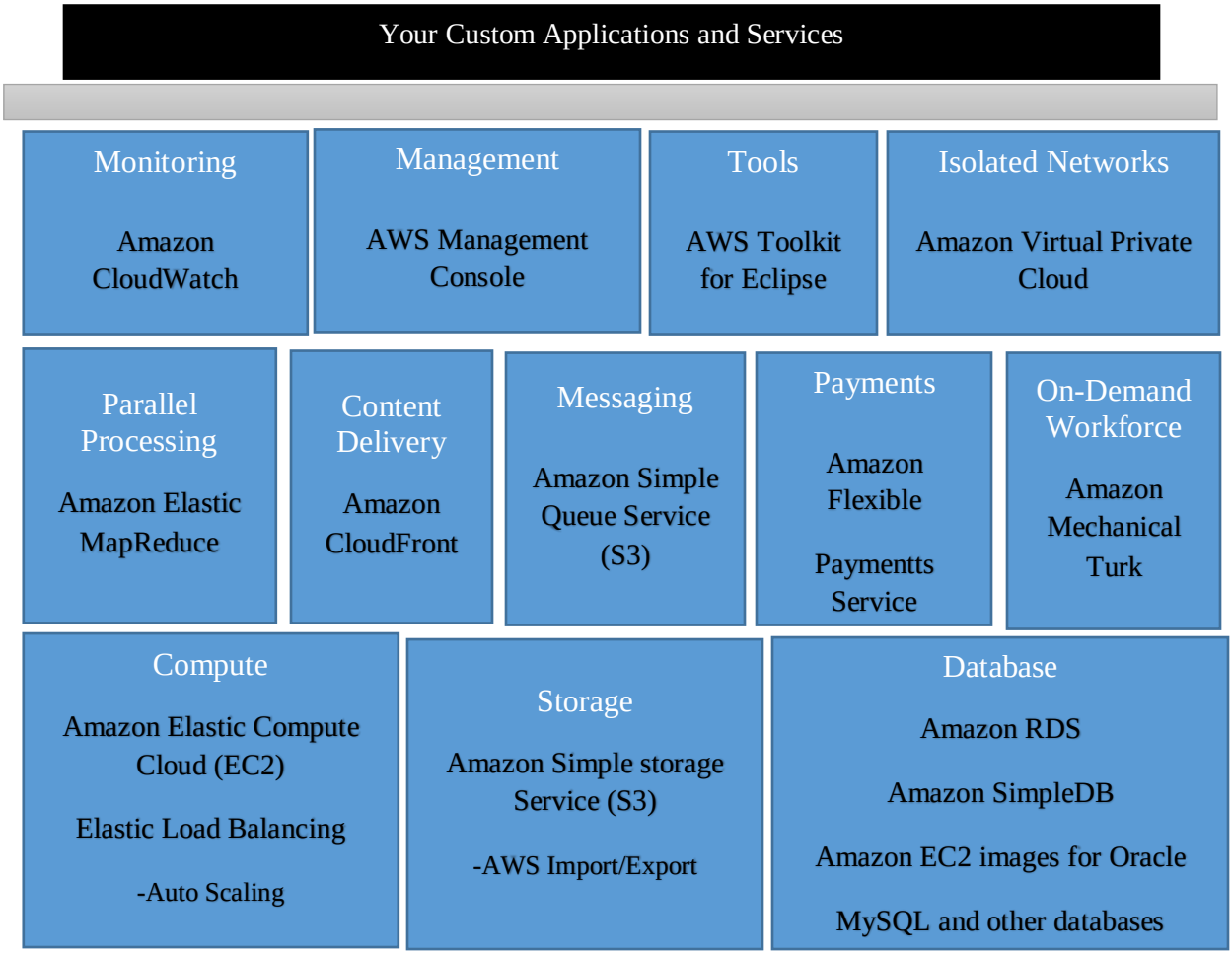


Figure 3.3: Main components of AWS (Understanding Amazon Web Services (AWS) | OracleApps Epicenter, 2019)

The architecture of Amazon web services is primarily made up of four parts: Elastic Compute Cloud (EC2), Simple Storage Service (S3), SimpleDB, and Simple Queue Service Amazon (SQS) (Padhy et al., 2011; Laxamaiah and Sharma, 2019).

- **Elastic Compute Cloud Amazon (EC2):** This allows a user to run numerous virtual servers on demand. It is scalable, efficient, protected and significantly affordable, as a user only pays for tools used (Laxamaiah and Sharma, 2019).
- **Simple Storage Service Amazon (S3):** This provides a flexible asset space for storing any data easily accessible over the internet. It is also used to back up and archive files (Sweda and Dubey, 2018).
- **Amazon SimpleDB:** This is a form of non-relational database that enables a user to store data. It uses a simple read/write command from the Application program interface (Ampaporn and Gertphol, 2015).
- **Simple Queue Service Amazon (SQS):** This is a service which passes a message among any cloud components (Laxamaiah and Sharma, 2019).

3.3.2 Microsoft Windows Azure

This is the major part of Microsoft cloud computing platform which was launched in 2010, it offers users with tools and platforms to create, operate and execute web applications on a huge, worldwide network.

Microsoft Windows Azure provides high performance, flexibility, and low service cost for IA AS, SAAS, and PAAS. It is accessible in over one hundred and forty countries and twenty eight regions (Al-Sayyed et al., 2019).

Migration of virtual machines on public cloud is simple because Microsoft windows azure is developed in windows server and shares almost the same softwares and application. Examples of some popular clients of Microsoft azure are Mazda, NBC sports, Xerox and FreshDirect (Purohit, 2017).

Figure 3.6 below shows the components of Microsoft azure which are compute, Data management, networking, Developer and IT services, identity and access, mobile, backup,

messaging and integration, compute assistance, performance, big compute and big data, media and commerce. This components help a user to explore available applications and services.

Figure 3.4: Components of Microsoft azure

The five essential features of Microsoft windows azure are: Compute, Storage, Content Delivery Network (CDN), SQL Azure and Fabric controller. (Padhy et al, 2011, Tajadod et al., 2012; Laxmaiah & Sharma 2019)

- **Compute:** This feature enables applications and services to be implemented on window azure platform. Compute in azure consists of web role for implementing web based apps, worker role for implementing of codes and Virtual machine for the migration of applications on window servers to azure (Tajane et al., 2018).
- **Storage:** It enables the storing of any size of data for a duration, there are three types of storage which are, blobs, table and queues. Blobs stores extensive tons of unorganized data, it's applicable to binary objects. Tables allows applications to function in an organized manner. Queues allow web based applications to connect with code implemented by a user (Tajane et al., 2018).
- **Content Delivery Network (CDN):** It improves overall quality by indexing content at places nearest to users. It creates accessibility since users have easy access to obtained data everywhere from the internet (Tajadod et al, 2012).
- **SQL Azure:** It offers data storage capacities comparable to Amazon simple storage service. It enables relational query to be rendered towards data in storage that can be organized, semi-organized or unorganized, users get connected in a number of different form like ADO.NET, PHP and Open Database Connectivity (Laxamaiah and Sharma, 2019).
- **Fabric controller:** This controls, oversee servers and organizes Microsoft windows azure applications and database development (Verma et al., 2018).

3.3.3 Google App Engine

This cloud platform is provided by Google was launched in 2011.Google App Engine is mainly a platform as service that allows a user to develop and execute applications through Google framework, thus removes the need for expensive acquisition and maintaining of database, as it is managed by Google (Tabot and Hamada, 2014; Narula et al, 2015).

The objective of GAE development is to boost the online presence by allowing several users create apps for the web. It does not charge anything to get started, charges are made based on the use of storage and bandwidth by a user at an affordable price range (Laxamaiah and Sharma, 2019).

It provides resources for data storage management, page monitoring, and asset utilization, testing and logging. It offers both PaaS and SaaS services. PaaS service such as GAE while SaaS services such as Gmail, Google doc, calendar and Google drive (Padhy et al, 2011).

Examples of some popular clients of Google cloud are Snapchat, Coca-Cola, Motorola and Airbus (Purohit, 2017).

Figure 3.7 below, shows the structure of Google app engine which include client capabilities containing the tools available for a user, cloud computing services and the support services in place.

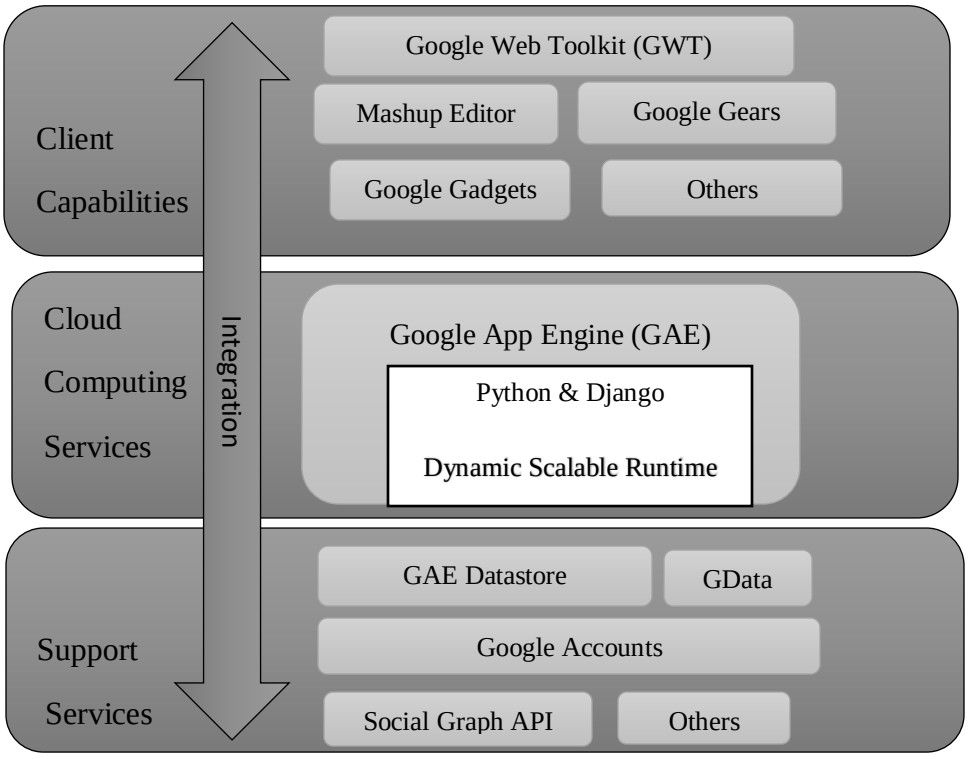


Figure 3.5: Structural design of Google App Engine (Laxmaiah and Sharma, 2019)

3.3.4. IBM Clouds

This is a cloud computing platform provided by information technology company IBM, which was launched in 2011. It offers both IaaS and PaaS as service to give a unified background IaaS provides services such as compute, storage, and networking over the web while PaaS help users build, maintain, operate and utilise different sorts of application. It became a force by acquiring companies providing cloud management and deployment services. It is widely regarded for customer relationship services, which includes a range of cloud users such as business and healthcare cloud (Koneru et al., 2018).

Examples of some popular clients of IBM clouds are Channel Pace, Silver Hook, and Jelastic (Purohit et al., 2017)

Figure 3.9 below shows the components of IBM cloud, the console for developing, displaying and controlling cloud assets, identity and access management safely verifies a user for service on the platform and manages accessibility to assets regularly on the cloud, catalog consists of the services offered by IBM, Search and Tagging is for sorting and defining assets, Provisioning layer is for controlling and managing resources and Billing ensures the correct use of pricing options and safe security from identity fraud.

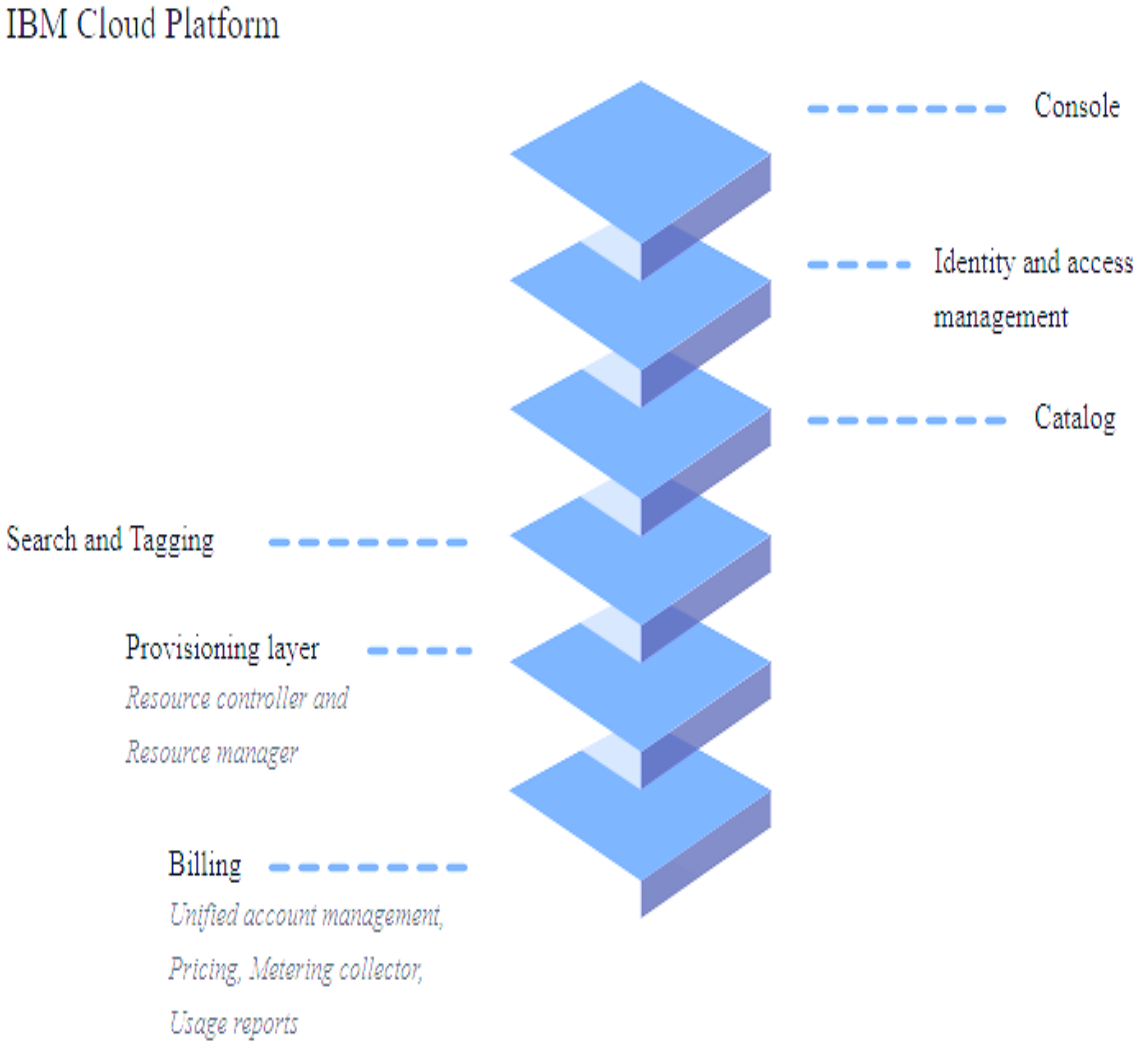


Figure 3.6: Features of IBM cloud Platform (IBM Cloud Docs, 2019).

CHAPTER FOUR

METHODOLOGY

This chapter explains the method adopted for the comparison of the chosen cloud platforms, comparison process, why the four cloud computing platforms were selected, the main features used for the comparison, the research process and research schedule.

4.1 Research Method

The research method used for this study is comparative method. The chosen features of the selected cloud computing platforms are compared by the author under the guidance of the supervisors. The cloud computing platforms were analysed and selected based on the features offered as services for users available on the website of the selected cloud platforms.

4.2 Selected Cloud Computing Platforms

The four major cloud computing platforms used for this research are Amazon web services (AWS), Microsoft windows azure (MWA), Google App Engine (GAE), and IBM cloud.

AWS and **Microsoft windows azure** were selected because they are the top two in terms of market shares and commonly adopted cloud platforms due to their prominence and the large number of services offered by them (Ajamal et al. 2018).

Google App Engine was selected because of its special PaaS, especially in terms of mobile apps and learning (Tabot and Hamada, 2014).

IBM cloud was selected because it's a fast growing cloud platform as shown in Table 4.3. RightScale conducted an annual survey in 2018 for cloud computing adoption which involved 997 tech experts from a wide range of enterprises and users of cloud which included AWS, Azure, Google and IBM. Figure 4.1 shows the result of the survey in percentages of respondents running applications, experimenting and plan to use the cloud platforms. AWS and Azure leads, while Google and IBM are the two closest competitors to them (Dignan, 2019)

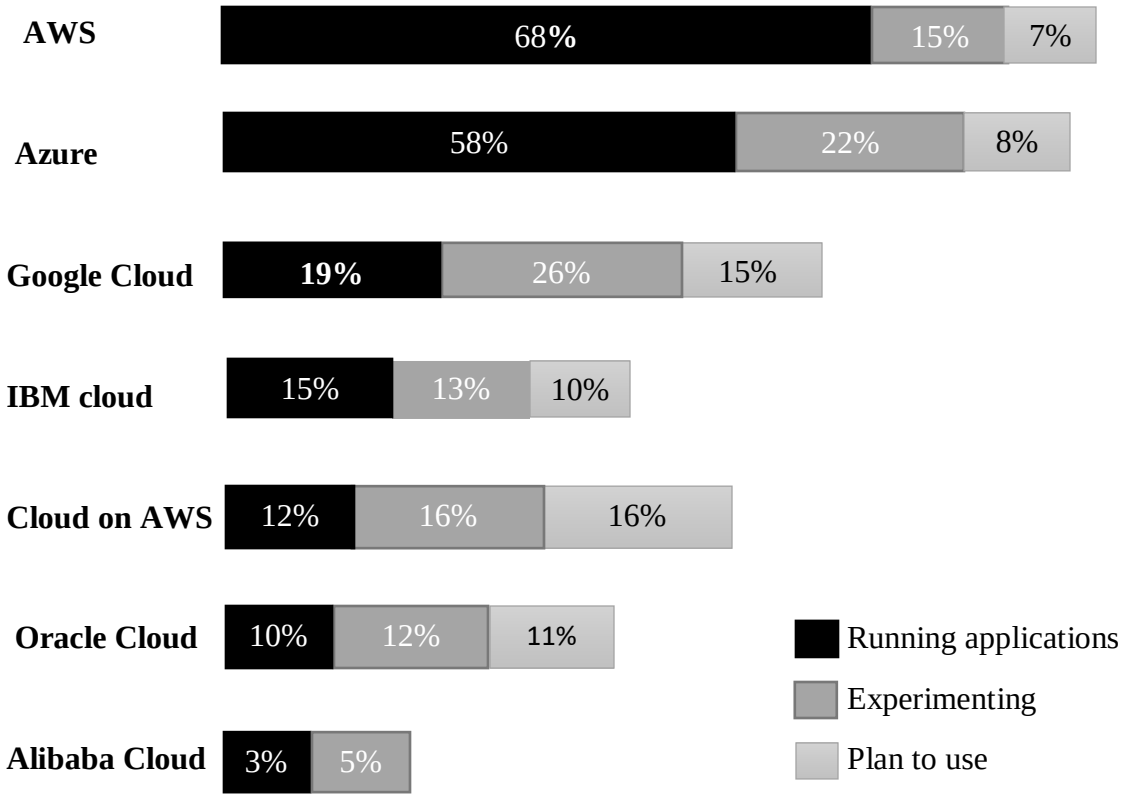


Figure 4.1: Enterprise public cloud adoption (Dignan, 2019)

A survey conducted in 2018 by Rightscale cloud report on Enterprise Scorecard adoption of AWS, Azure, Google and IBM. Table 4.3 below, shows there is competition within this four popular cloud platforms in terms of adoption, year over year (YoY) growth in adoption, adoption of beginners, and virtual machine (VM) footprints. Even though AWS holds a major percentage scores with enterprises, Azure is fast growing with a strong number of adoptions. Google and IBM are growing steadily as well and lead in terms year to year growth of VMs (Weins, 2019)

Table 4.1: AWS vs Azure vs Google vs IBM Enterprise Scorecard (Weins, 2019)

Area	AWS	AZURE	GOOGLE	IBM
% Adoption	**68%**	**58%**	19%	15%
YoY Growth in Adoption	15%	**35%**	26%	**50%**
% Adoption in Beginners	**47%**	**49%**	18%	14%
% with Footprint > 50 VMs	**58%**	**44%**	17%	14%
YoY Growth in Footprint > 50 VMs	14%	38%	**42%**	**56%**

4.3 Main Comparative Features Used

The features used for this comparative study were chosen based on the current information made available on the websites of the selected platforms, related research and logically by the author under the guidance of the supervisors.

- ***Cloud service type:*** This shows which cloud service such as IaaS, PaaS and SaaS are offered by the selected cloud platforms. Some of the selected platforms offer all three service type (Laxmaiah and Sharma, 2019).
- ***Cloud storage:*** This enables users to store data in the cloud easily accessed entirely via the internet from anywhere on various kind of device (Abdalla and Varol, 2019). Cloud storage space is now an attraction for customers to choose a cloud platform (Ali Rahman et al., 2018).
- ***Database supported:*** This provides support for handling different kind of database such as relational, SQL, No SQL, Data warehouse, in-built memory cache (Wahid and Banday, 2018).
- ***Security mechanism:*** This is the security measures put in place by the cloud platforms to secure the integrity, privacy and confidentiality of a customer's data (Kapil et al., 2017)

- ***Service level agreement (SLA):*** This is the contract signed by the cloud platforms and a user. It is necessary for users to receive assurances from providers on the provision of services. Cloud users do not have control over the physical assets, they need to ensure the reliability, usability, transparency, and efficiency of such services (Kapil et al., 2017).
- ***Languages supported:*** This shows the programming languages that the cloud platforms application supports such as Java, Python, C#, VB.NET which could be helpful to a developer or a user (Laxmaiah and Sharma, 2019).
- ***Pricing method:*** This shows the payment method available in the cloud platform either as Pay-as-you-go based which a user pays for as the use the service, subscription based which a user pays a minimum price to subscribe for a certain duration and free tier which a user use a service for free for a particular durations (Al-Sayyed et al., 2019).
- ***Virtualization method:*** This enables the running of two or more operating system on a single machine called VM. Virtualization helps in the migration from one machine to another. It aims to save power and reduce costs on physical hardware. It is usually classified as hosted hypervisor or bare-metal virtualization (Jain and Choudhary, 2016)
- ***Mobile Services:*** This provides services for mobile apps development and testing, user monitoring, notifications, identification, Application programming interface management (Wahid and Banday, 2018).
- ***Internet of Things (IoT):*** This feature provides services that are connected to IoT platform that allows appliances to connect seamlessly and safely to the internet in terms of communication with applications from the cloud (Hyseni and Ibrahimi, 2017).
- ***Data Backup and Recovery:*** This shows features available to automatically back up and recover data or a user has to implement backup and recovery of data manually (Dutta and Dutta, 2019).
- ***User Interface:*** This shows the type of interface for a developer and an end user by the cloud platforms for set up and implementation functions such as web based, Application Programming Interface (API) and Console (Islam and Rehman, 2013).

Table 4.2 below, shows the twelve chosen features used for the comparison which were used for the comparison of cloud platforms by other authors in previous related studies. This features help to determine the choice of potential users, therefore it needs to be analysed and compared to make the decision easier.

Table 4.2: Selected features for comparison and authors

FEATURES	REFERENCE
Cloud service type	Laxamaiah and Sharma, 2019
Cloud storage	Abdalla and varol, 2019
Database Supported	Wahid and Banday, 2018
Security mechanism	Kapil et al., 2017
Service Level Agreement	Al-Sayedd et al., 2019
Languages Supported	Laxamaiah and Sharma, 2019
Pricing method	Al-Sayedd et al., 2019
Virtualization method	Jain and Choudhary, 2016
Mobile services	Wahid and Banday, 2018
Internet of Things	Hyseni and Ibrahimi, 2017
Data backup and recovery	Dutta and Dutta, 2019
User Interface	Islam and Rehman, 2013

4.4 Research Process

The research process involved eight steps as shown in Figure 4.4, which are Literature review of the study, studying related research, getting approval from supervisor, gathering of data, data analysis, developing of comparison and theoretical explanation, description of findings and giving a report.

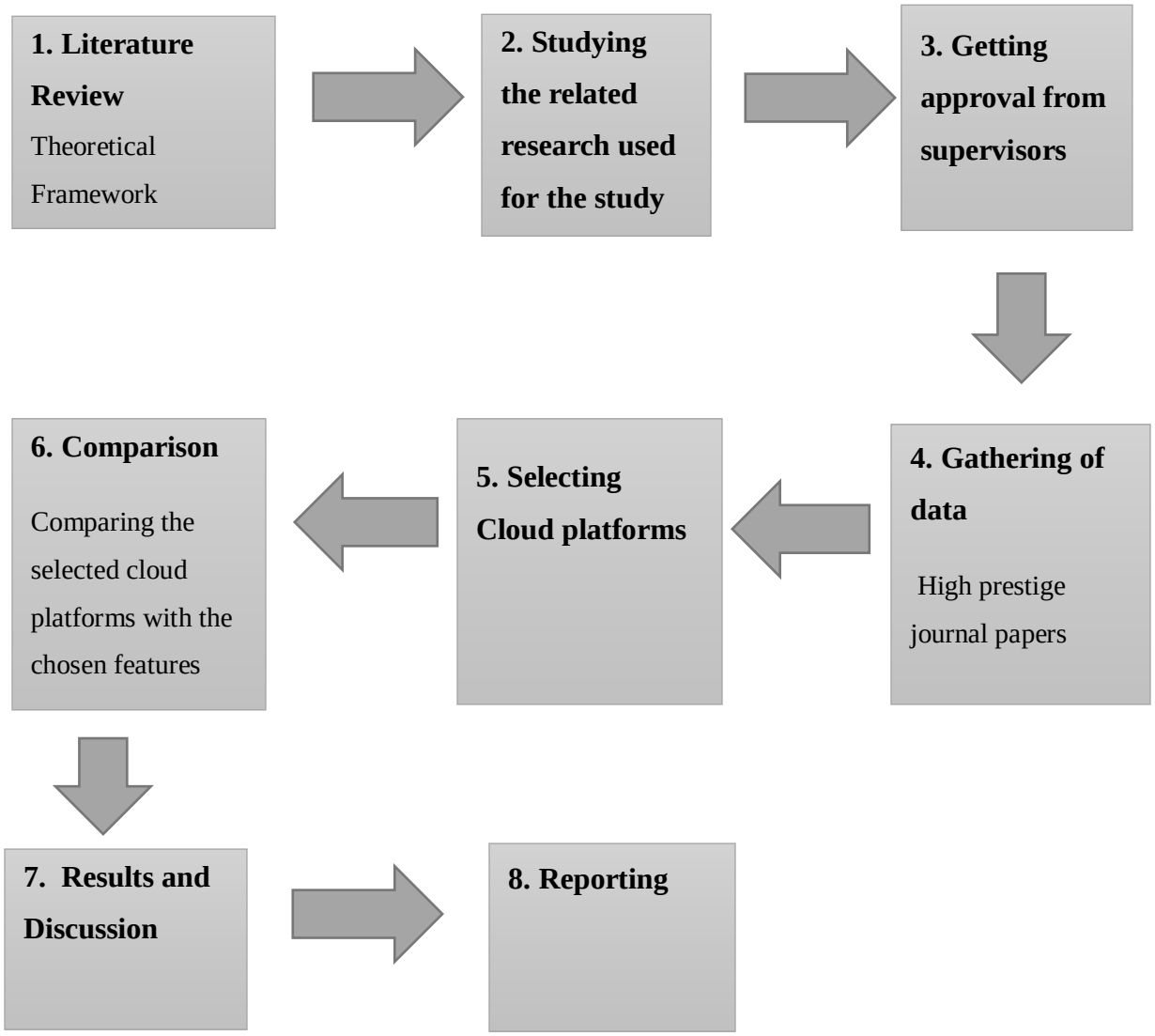


Figure 4:2: Research process

4.5 Research Schedule

Carrying out a study can be demanding. That's why it is very important to schedule task to be able to finish on time and meet deadline. This study started in August and was finished in fall of December. Table 4.3 shows the task name and the number of days it took to be completed while Figure 4.5 shows the steps taken for each task and dependencies in a Gantt chart

Table 4.3: Task schedule of the study

TASK NAME	**DURATION (DAYS)**
Literature review	119
Select Thesis topic	5
Write proposal	1
Submission of proposal and approval	3
Gathering of data	2
Data analysis	14
Write Thesis	40
Submission of Thesis to supervisors	1
Correction and modifying Thesis	14
Thesis defense and final correction	7
Total number of days	**119**

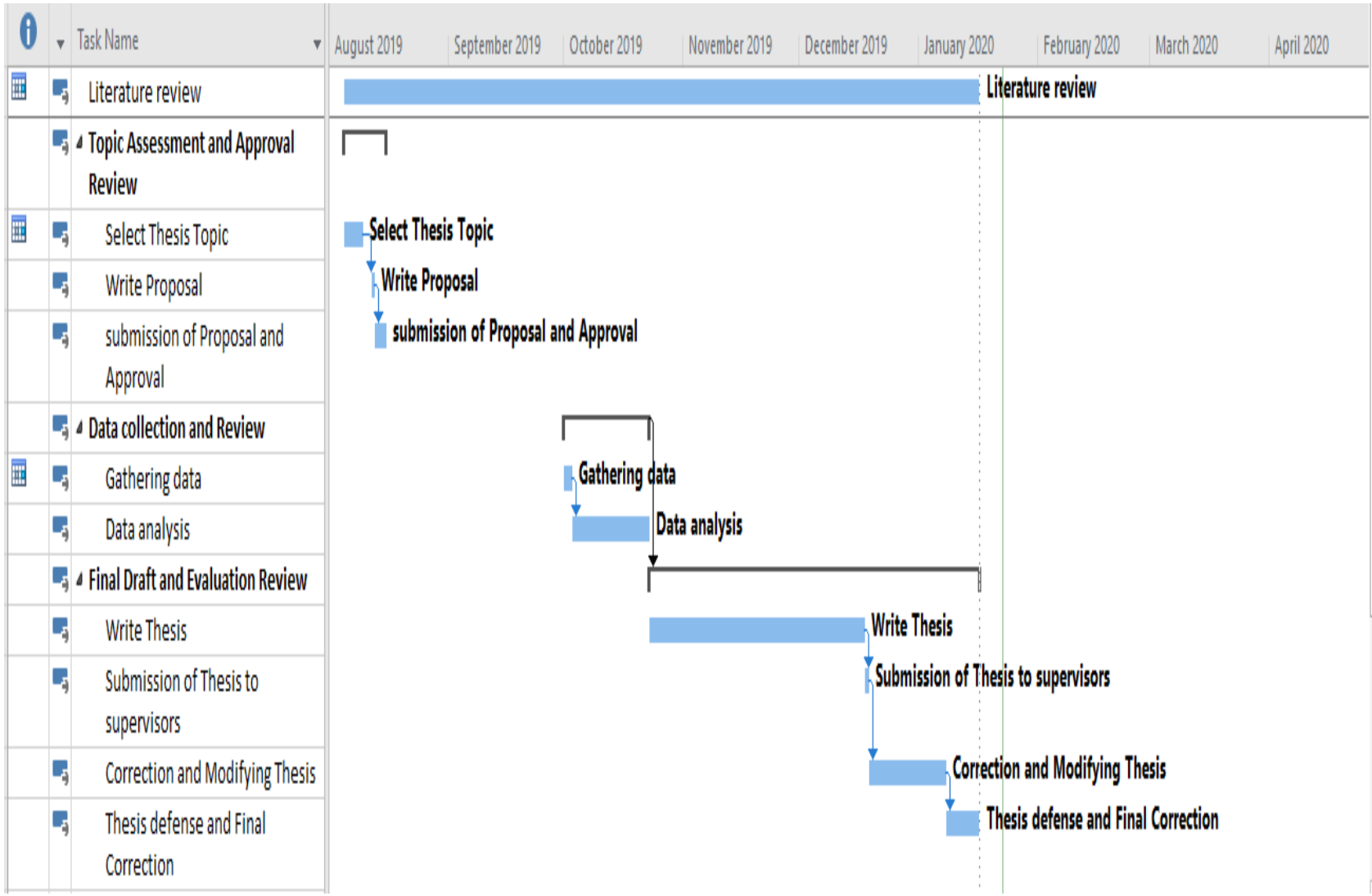


Figure 4.3: Research schedule of the study

CHAPTER FIVE

RESULTS AND DISCUSSION

This chapter explains the results from the comparison of the features and analysed them to previous related research while addressing the missing gap and discussing the result outcomes.

5.1 Results

The result of the comparison of these platforms based on the main features selected shows the different features used by them, while some are the comparable, others have superior qualities. Each feature used for comparison will be discussed in all four platforms before listed in a tabular form.

1. **Cloud Service Type**

   This explains the type of services provided by the four selected cloud platforms which includes infrastructure, platform and software as a service. Most of platforms offer all three available services.

   AWS: Offers all three service types, Infrastructure as a service, platform as a service and recently launched software as a service. It is popularly known for its top notch Infrastructure as a service solution worldwide though.

   Microsoft Windows Azure: Offers all three service type just like AWS, Infrastructure as service such as Virtual machines, web hosting, test and development, Platform as a service such as development framework and Software as a service such as email, calendars and Microsoft tools.

   Google App Engine: Primarily offers platform as a service. Which makes it unique than others in this regard. It could be used by developers to build a SaaS.

   IBM cloud: Offers all three service type Infrastructure as a service, platform as a service and software as a service just like AWS and Azure.

2. **Storage**

This shows the type of storage options available for a user in the selected cloud platforms that meets their various requirements.

AWS: Provides users with various options for storing data such as Simple storage service for Big Data storage and backup and recovery, Elastic block storage for relational and NoSQL database, enterprise applications, Elastic file system for tasks on Linux, Storage gateway for hybrid and archival storage all at affordable prices.

Microsoft Windows Azure: Provides users with numerous options for data storage such as Blob for unorganized data, File for sharing files, Queue for efficiently scaling congested applications, Disk for support of virtual machines, and Data Lake for Big data analytics. Queue and Data Lake storage provides options for high volume and vital task similar to AWS storage gateway.

Google App Engine: Provides users with simple storage options such as Persistent disk, cloud storage, Transfer appliance and services. Unlike AWS and Azure, Google App Engine does not have for Big Data.

IBM clouds: Provides users with three storage options, Object for unorganized data like Azure's Blob, File and Block storage for local disk.

3. **Database Support**

This explains the type of database options provided by the selected cloud platforms to a user. It is mostly classified into relational and non-relational database.

AWS: Provides users with different types of databases such as Aurora, RDS, Elastic Cache, Dynamo DB, Neptune, Redshift, and migration service for relational, extra memory and data migration service.

Microsoft Azure: Provides users with mostly SQL supported databases such as SQL, MySQL, PostreSQL, Data warehouse, Table and CosmoDB.

Google App Engine: Provides users with SQL and NOSQL supported database such as SQL, Spanner, Datastore and Bigtable.

IBM clouds: Provides users with SQL supported databases such as SQL, PostreSQL, Lift, MYSQL and Cloudant.

4. **Security mechanism**

This explains the security feature available in the selected cloud platforms for the protection of a users' data.

AWS: There are security features such as Amazon GuardDuty, Amazon Macie, AWS shield and AWS web Applications in place to detect threat, protect data, safeguards apps running on AWS and web applications Firewall.

Microsoft Windows Azure: Security center provides unparalleled security and protection from threats in Azure platform.

Google App Engine: Provides Cloud Data Loss Prevention for managing sensitive data and Security scanner for scanning for vulnerabilities.

IBM cloud: Provides Network security for the protection of servers and users from malicious attacks. Also offers some monitoring tools.

5. **Service Level Agreement Availability (SLA)**

This explains the service level agreement available in the selected cloud platforms for a user to enjoy the full benefit of the service.

AWS: It offers 99.9% monthly for services during a monthly billing (Al-Sayedd et al., 2019).

Microsoft Windows Azure: It guarantees at least 99.9% for basic and premium services (Al-Sayedd et al., 2019).

Google App Engine: It offers 99.95% monthly uptime to a user similar to Azure (Laxamaiah and Sharma, 2019).

IBM cloud: It provides a 99.99% availability similar to that of AWS (Laxamaiah and Sharma, 2019).

6. **Languages Supported**

This shows the programming languages supported by the selected cloud platforms for a developer.

AWS: It supports any language. This makes AWS to be a stand out for developers.
Microsoft Windows Azure: It supports C#, Java, Python, PHP.
Google App Engine: It supports Java, Python, PHP, Go, Node.js.
IBM cloud: It supports Java, Python, PHP, and Node.js.

7. **Pricing Method**

This explains the pricing or payment method available to a user in the selected cloud platforms such as pay as you use, subscription, free trial.

AWS: Offers Pay as you use paying for services you need only, Pay less by using more gives users discount as the use more services, save when you reserve gives users a bigger discount when they make a big upfront payment, free tier offers trials, 12 months free services and some services that are always free to users.
Microsoft Windows Azure: offers pay as you use for services you use, subscription based, Microsoft Enterprise agreement, Azure Hybrid Benefit using Windows server and SQL licences at a cheaper rate.
Google App Engine: offers pay as you use for services used, free tier offers 12 months of free services and some services are always free to eligible users subject to change.
IBM cloud: offers pay as you use for only services used, subscription based for a longer period of time at a discounted rate, Lite offers free access to over 40 IBM services and reserved instances for 1 year or 3 years with discount and guaranteed.

8. **Virtualization Method**

This shows the virtualization process available in the selected cloud platforms.

AWS: Virtualization is based on Kernel- based Virtual machine (KVM) for Amazon Elastic compute.

Microsoft Windows Azure: Uses Hyper-V hypervisor to create virtual machine.

Google App Engine: Google compute engine Kernel- based Virtual machine (KVM).

IBM cloud: Uses bare-metal hypervisors for virtualization.

9. **Mobile Services**

This shows the mobile services offered by the selected cloud platforms available to a user.

AWS: AWS Amplify is the feature used for building mobile and web.

Microsoft Windows Azure: Offers features such as Mobile Apps for a developer to build and host apps, notification hubs, Azure maps.

Google App Engine: Offers features to build mobile and android.

IBM cloud: Offers features such as IBM Mobile Foundation, IBM cloud App ID and IBM Push Notification to build mobile and web apps.

10. **Internet of Things (IoT)**

This shows the internet of things features offered by the selected cloud platforms.

AWS: Offers numerous IoT features such as IoT core, IoT Analytics, IoT 1click, IoT Button, IoT device Defender and IoT device Management enabling a user create IoT applications for nearly any number of devices. AWS is far ahead of all its competitors in terms of IoT.

Microsoft Windows Azure: Offers IoT features such as IoT Edge, IoT Hub, Time series Insight, Stream analytics helping a user add IoT to any device and platform on the same framework. It is AWS strongest rival to date.

Google App Engine: Offers IoT core which connects and manages IoT devices. It is still in early stage and behind its competitors.

IBM cloud: Offers IBM Edge Computing, IBM Watson Platform and Weather data APIs for connecting devices and data to datasets and APIs from weather.

11. Data Backup and Recovery

This shows the data backup and recovery systems in place in the selected cloud platforms.

AWS: Provides Amazon glacier for data archiving and long term backup for at a very low cost. Users are charged $1 per terabyte per month.

Microsoft Windows Azure: Provides options such as Archival storage, Recovery backups and Site recovery for long term data backup and recovery.

Google App Engine: Provides Nearline and Coldline for backup, archival and recovery.

IBM cloud: Provides IBM cloud backup for backup and recovery of data.

12. User Interface

This shows the type graphical user interface available to a user by the selected cloud platforms such as web based interface, application program interface and console.

AWS: Offers users' easily accessible web based portal on a computer or mobile device.

Microsoft Windows Azure: Offers a web based interface, Application Program Interface (API) for developers and Azure console.

Google App Engine: Offers a web based interface, Application Program interface for developers and Google.

IBM cloud: Offers a web based user interface easily accessible.

Table 5.1 below, shows a tabular summary of the comparison of the features offered by the selected cloud platforms, AWS, Microsoft Windows Azure, Google App Engine, and IBM cloud.

Table 5.1: Summary of Comparison of cloud platforms

	AWS	MICROSOFT WINDOWS AZURE	GOOGLE APP ENGINE	IBM CLOUDS
Cloud service Type	IAAS SAAS PAAS	IAAS SAAS PAAS	PAAS	IAAS SAAS PAAS
Cloud storage	Simple storage service Elastic block storage Elastic file system Storage gateway	Blob File Queue Disk Data Lake	Persistent disk Cloud storage Transfer appliance and services	Object file block
Database supported	Aurora Relational Database service Elastic Cache Dynamo DB Neptune Redshift Migration service	SQL MySQL PostgreSQL Data warehouse Table Cosmo DB	SQL Spanner Datastore Bigtable	SQL PostgreSQL Lift MySQL for Cloud Cloudant
Security mechanism	Amazon GuardDuty Amazon Macie AWS Shield AWS Web Application Firewall	Security center	Cloud Data Loss Prevention Security scanner	Network security

Table 5.1: *Continue*

Service Level Agreement (SLA) availability	99.9% monthly uptime	At least 99.95% uptime	At least 99.99% uptime	At least 99.99% uptime
Supported Languages	Any	C# Java Python	Java Python Node.js PHP Go	Java Node.js PHP Python
Pricing method	Pay as you use Pay less by using more Save when you reserve Subscription AWS Free tier: offers services always free, expires after 12 months	Pay as you use Subscription Microsoft Enterprise agreement Azure Hybrid Benefit	Pay as you use GCP free tier: free use of products during and after trial but subject to change.	Pay as you use Subscription Lite: offers free service to over 40 services Reserved instances

Table 5.1: *Continue*

Virtualization Method	Amazon Elastic compute utilizes Kernel-based Virtual Machine (KVM) as hypervisor	Utilizes Hyper-V hypervisor	Google compute engine utilizes Kernel-based Virtual Machine (KVM) as hypervisor	Bare-metal virtualization
Mobile services	AWS Amplify	Mobile Apps Notification Hubs Azure maps	Google Apps, Android	IBM Mobile Foundation App ID IBM Push Notification
Internet of Things (IoT)	IoT Core IoT Analytics IoT 1 click IoT Button IoT Device Defender IoT Device	IoT Edge, IoT Hub Time series Insight Stream analytics	IoT Core	IBM Edge Computing IBM Watson platform Weather data APIs
Data Backup and Recovery	Amazon Glacier	Archival storage Recovery backups Site recovery	Nearline(regularly accessible data) Coldline(irregularly accessible data)	IBM cloud Backup
User Interface	Web-based	Web-based Application Program Interface(API), Console	Web-based Application Program Interface(API), Console	Web-based

5.2. Discussion

The results shows that three of these cloud platforms, AWS, Microsoft Windows Azure and IBM cloud offer the three cloud service type which are Infrastructure as a service, platform as a service and Software as a service compared to (Laxamaiah and Sharma, 2019) who excluded Software as a service for AWS and Microsoft Windows Azure. Even though it agrees that Google App Engine only offers Platform as a service but developers can use GAE to build Software as a service. In terms of storage, database support and backup and recovery, the result supports the finding (Dutta and Dutta, 2019) for AWS, Microsoft Windows Azure and Google, as well as close the knowledge gap that Azure stands out in terms of these services as it offers customers with the highest variety of database and has the only backup recovery system among these three cloud platforms followed closely by AWS while Google does not have a long term backup and recovery system yet. This should make it more appealing to users seeking a cloud platform for storing high volume data, vital tasks and archival storage. All four cloud platforms provide SQL supported databases.

In security terms, they all have measures in place to protect the integrity, confidentiality and privacy of users' data, but AWS and Microsoft Windows Azure have better security features in place than Google as also suggested (Dutta and Dutta, 2019). IBM cloud is also behind in security in comparison to the three other cloud platforms (Deshmukh and Mishra, 2018). For languages supported and SLA, the result agrees with (Laxamaiah and Sharma, 2019), only AWS supports any language while the others support only certain languages. The common languages used by all four cloud platforms are Java and Python. But there is only slight difference in SLA, the result shows Google App Engine has a 99.99% monthly uptime availability in comparison to 100% uptime as indicated in their later study. When it comes to pricing method, there is a big difference from (Dutta and Dutta, 2019), AWS and Microsoft Windows Azure offer more but complex payment structure involving a range of factors, even though the provide a cost calculator. Microsoft Windows Azure offers benefits to users of Winder servers. Google and IBM cloud provide a simpler and friendly pricing method. Google also offers the best free tier

service. If a user is seeking a cost effective cloud service with strong development prospect, this should appeal.

This study also analyzed features for comparison such as Virtualization, mobile services, IoT and User Interface all missing (Purohit, 2017; Deshmuhk and Mishra, 2018; Laxamaiah and Sharma, 2019; Dutta and Dutta, 2019). AWS and Google App Engine both use Kernel- based Virtual machine (KVM) for virtualization. Microsoft Windows Azure uses Hyper-V hypervisor to run virtual machines. IBM cloud is based on Bare-metal hypervisors or VMware. Recently Google and Microsoft enable Nested Virtualization, running of virtual machine (VM). For mobile services, the all offer the opportunity to create mobile and web Apps, Notification Push or Hubs, and maps which is beneficial to developers and users respectively. AWS leads the way in IoT, with the many IoT services it helps leverage a variety of IoT business applications built to empower businesses with the workplace of the future. Microsoft's IoT edge is targeted towards planning and business intelligence. Google's only IoT is still in the testing phase. IBM clouds also provide IoT services such as Weather Data APIs which integrates data from weather companies.

All four selected cloud platforms use a web based interface for access by a user, even though Microsoft azure and Google also use Application Program Interface (API) and Console as access to developers

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Cloud computing is very important as it enables businesses to be more flexible by accessing stored data via the internet from any location at any given time, offers reduced cost on a pay as you use basis, boosts agility by providing infrastructure, backup and recovery and software management at an affordable rate to individuals, companies, institutions and organizations. This study reviewed some previous comparative study on popular cloud platforms and widen the gap on the features compared. The study also compared four widely adopted cloud platforms which includes AWS, MWA, GAE, and IBM clouds based on commonly shared features.

The result of the comparison showed that AWS has a vast global reach and market shares with its flexible and wide range of services, it should appeal to large companies seeking a cloud platform. Microsoft windows azure offers a hybrid solution, easy first time cloud migration, it is suitable for start-ups and the best fit for organizations using Windows. Google App Engine offers a cost effective platform and has huge development prospect, best fits developers of cloud based software and apps. IBM clouds adoption rate is growing rapidly due to its unique virtualization and private cloud services it offers.

This study is helpful to potential users of cloud platform such as small mid-size enterprises, developers and large companies for selecting suitable cloud platforms that satisfies their specification, as it analysed the features each cloud offers more quality service even though the choice rests solely on the user.

6.2 Recommendations

This study can be extended to other cloud computing platforms, and more features can be compared such as Machine learning, Artificial intelligence, Blockchain and many others as cloud computing keeps adding more features to its users. The economic impact of cloud platforms is an area yet to be explored by researchers as well.

REFERENCES

Abdalla, P., and Varol, A. (2019). Advantages to disadvantages of cloud computing for small-sized business. *In Proceedings of the 7th International Symposium on Digital Forensics and Security*. Barcelos, Portugal. IEEE.

Agarwal, A., Siddharth, S., and Bansal, P. (2016). Evolution of cloud computing and related security concerns. *In Proceedings of the Symposium on Colossal Data Analysis and Networking*. Indorie, India: IEEE.

Alam, M., Pandey, M., and Rautaray, S. (2015). A comprehensive survey on cloud computing. *International Journal of Information Technology and Computer Science*, *7*(2), 68-79. doi: 10.5815/ijitcs.2015.02.09

Ali Rahman, F., Ferdiana, R., and Kusumawardani, S. (2018). Integrated cloud storage on paperless thesis examination. *In Proceedings of the 4th International Conference on Science and Technology*. Yogyakarta, Indonesia: IEEE.

Aljamal, R., El-Mousa, A., and Jubair, F. (2018). A comparative review of high-performance computing major cloud service providers. *In Proceeding of the 9th International Conference on Information and Communication Systems* (pp. 181-186). Irbid, Jordan: IEEE.

Al-Sayyed, R. M. H., Hijawi, W. A., Bashiti, A. M., AlJarah, I., Obeid, N.,and Al-Adwan, O. Y. A. (2019). An Investigation of Microsoft Azure and Amazon Web Services from Users' Perspectives. *International Journal of Emerging Technologies in Learning*, 14(10), 217-241. doi:10.3991/ijet.v14i10.9902

Ampaporn, P., and Gertphol, S. (2015). Performance measurement of SimpleDB APIs for different data consistency models. *In Proceedings of the International Computer Science and Engineering Conference*. Chiang Mai, Thailand: IEEE.

Bari, I., Babu, S., Iqbal, M., Saleem, Y., and Masood, Z. (2015). Cost and performance based comparative study of top cloud service providers. *International Journal of Computer Science and Information Security*, *13*(12), 172-177.

BV, R., Baliga, V., and kumar, A. (2013). A comparative study of Amazon Web Service and Windows Azure. *International Journal of Advanced Computer Research*, *3*(3), 80-88.

Čandrlić, G. (2019). Cloud Computing - Types of Cloud. Retrieved 18 October 2019, from https://www.globaldots.com/blog/cloud-computing-types-of-cloud

Chandel, S., Ni, T., and Yang, G. (2018). Enterprise cloud: Its growth & security challenges in China. *In Proceedings of the 5th IEEE International Conference on Cyber Security and Cloud Computing* (pp. 144-152). Shanghai, China: IEEE.

Dignan, L. (2019). Top cloud providers 2018: How AWS, Microsoft, Google, IBM, Oracle, Alibaba stack up | ZDNet. Retrieved 29 November 2019, from https://www.zdnet.com/article/top-cloud-providers-2018-how-aws-microsoft-google-ibm-oracle-alibaba-stack-up/

Deshmukh, D., and Mishra, A. (2018). Comparative study between existing cloud service providers. *International Journal of Advanced Research in Computer Science*, *9*(2), 537-539. doi: 10.26483/ijarcs.v9i2.5722

Dutta, P., and Dutta, P. (2019). Comparative study of cloud services offered by Amazon, Microsoft and Google. *International Journal of Trend in Scientific Research and Development*, *3*(3), 981-985. doi: 10.31142/ijtsrd23170

Dordevic, B., Jovanovic, S., and Timcenko, V. (2014). Cloud Computing in Amazon and Microsoft Azure platforms: Performance and service comparison. *In Proceeding of the 22nd Telecommunications Forum Telfor* (pp. 931-934). Belgrade, Serbia: IEEE.

Ferriman, B., Hamed, T., and Mahmoud, Q. (2015). Storming the cloud: A look at denial of service in the Google App Engine. *In Proceedings of the International Conference on Computing, Networking and Communications* (pp. 363-368). Garden Grove, CA: IEEE.

Giovanoli, C. (2019). Cloud Service Quality Model: A cloud service quality model based on customer and provider perceptions for cloud service mediation. *In Proceedings of the 9th International Conference on Cloud Computing and Services Science* (pp. 241-248) Olten, Switzerland: SCITEPRESS.

Höfer, C. N., and Karagiannis, G. (2011). Cloud computing services: taxonomy and comparison. *Journal of Internet Services and Applications,* 2(2), 81–94. doi:10.1007/s13174-011-0027-x

Hyseni, L., and Ibrahimi, A. (2017). Comparison of the cloud computing platforms provided by Amazon and Google. *In Proceedings of the IEE Computing Conference* (pp.236-243). London, UK: IEEE.

Islam, N., and Rehman, A. (2013). A comparative study of major service providers for cloud computing. *In Proceedings of the 1st International Conference on Information and Communication.* Karachi, Pakistan.

Jain, N., and Choudhary, S. (2016). Overview of virtualization in cloud computing. *In Proceedings of the Symposium on Colossal Data Analysis and Networking*. Indore, India: IEEE.

K, M., Laxmaiah, M., and Sharma, Y. (2019). A comparative study on Google App Engine Amazon Web Services and Microsoft Windows Azure. *International Journal of Computer Engineering & Technology*, *10*(1), 54-60. doi:10.34218/Ijcet.10.1.2019.007

Kaur, A., Raj, G., Yadav, S., and Choudhury, T. (2018). Performance evaluation of AWS and IBM cloud platforms for security mechanism. *In Proceedings of International Conference on Computational Techniques, Electronics and Mechanical Systems Proceedings* (pp. 516-520). Belgaum, India: IEEE.

Kaur, A., Singh, V., and Singh Gill, S. (2018). The future of cloud computing: opportunities, challenges and research trends. *In Proceedings of the 2nd International Conference on I-SMAC* (pp. 213-219). doi: 10.1109/i-smac.2018.8653731

Kimmy. (2013). A comparative study of clouds in cloud computing. *International Journal of Computer Science & Engineering Technology*, *4*(6), 843-849.

Koneru, A., Naga Sai Rajani Bhavani, N., Purushottama Rao, K., Sai Prakash, G., Pavan Kumar, I., and Venkat Kumar, V. (2018). Sentiment analysis on top five cloud service providers in the market. *In Proceedings of the 2nd International Conference on Trends in Electronics and Informatics* (pp. 293-297). Tirunelveli, India: IEEE.

Li, A., Yang, X., Kandula, S., and Zhang, M. (2010). CloudCmp. *In Proceedings of the 10th Annual Conference on Internet Measurement* (pp. 1-14). New York, NY: ACM.

Liu, F., Tong, J., Mao, J., Bohn, R., Messina, J., Badger, M., and Leaf, D. (2020). NIST Cloud Computing Reference Architecture. Retrieved 10 January 2020, from https://www.nist.gov/publications/nist-cloud-computing-reference-architecture

Mell, P. M., and Grance, T. (2011). The NIST definition of cloud computing. doi:10.6028/nist.sp.800-145

Murty, J. (2008). *Programming Amazon Web Services*. Beijing: O'Reilly.

Narula, S., Jain, A., and Prachi. (2015). Cloud Computing Security: Amazon Web Service. *In Proceedings of the 5th International Conference on Advanced Computing & Communication Technologies* (pp. 501-505). Haryana, India: IEEE

Neto, M. (2019). A brief history of cloud computing - Cloud computing news. Retrieved 3 December 2019, from https://www.ibm.com/blogs/cloud-computing/2014/03/18/a-brief-history-of-cloud-computing-3/

Padhy, R., Patra, M., and Satapathy, S. (2011). X-as-a-Service: Cloud Computing with Google App Engine, Amazon Web Services, Microsoft Azure and Force.com. *International Journal of Computer Science and Telecommunications*, *2*(9), 8-16.

Purohit, R. (2017). Comparative analysis of few cloud service providers considering their distinctive Properties. *International Journal of Advanced Research in Computer Science*, *8*(0976-5697), 1908-1916. doi: 10.26483/ijarcs.v8i5.4018

Sahu, Y., and Pateriya, R. (2013). Cloud Computing Overview with Load Balancing Techniques. *International Journal of Computer Applications*, *65(24*), 40-44. doi: 10.5120/11236-6559

Sarma, P., Kalita, C., and Deka, V. (2019). A Survey on Load Balancing Algorithms in Cloud Computing. *International Journal of Computer Sciences and Engineering*, *7*(6), 169-176. doi: 10.26438/ijcse/v7i6.169176

Sharma, A., Ahmad, A., Singh, D., and Patni, J. (2016). CloudBox — a virtual machine manager for KVM based virtual machines. *In Proceedings of the 2nd International Conference on Next Generation Computing Technologies (pp.588-594)*. Dehradun, India: IEEE.

Swedha, K., & Dubey, T. (2018). Analysis of Web Authentication Methods Using Amazon Web Services. *In Proceedings of the 9th International Conference on Computing, Communication and Networking Technologies*. Bangalore, India: IEEE.

Tabot, A., and Hamada, M. (2014). Mobile Learning with Google App Engine. *In Proceedings of the 8th IEEE International Symposium on Embedded Multicore/Manycore Socs (*pp. 63-67). Aizu-Wakamatsu, Japan: IEEE.

Tajadod, G., Batten, L., and Govinda, K. (2012). Microsoft and Amazon: a comparison of approaches to cloud security. *In Proceedings of the 4th IEEE International Conference on Cloud Computing Technology And Science* (pp. 539-544). Taipei, Taiwan: IEEE.

Tajane, K., Dave, S., Jahagirdar, P., Ghadge, A., and Musale, A. (2018). AI base chat-bot using Azure cognitive services. *In Proceedings of the 4th International Conference on Computing Communication Control and Automation.* Pune, India: IEEE.

Verma, A., Malla, D., Choudhary, A., and Arora, V. (2019). A Detailed Study of Azure Platform & Its Cognitive Services. *2019 International Conference on Machine Learning, Big Data, Cloud and Parallel Computing (pp. 129-134)*. Faridabad, India: IEEE.

Wang, L., von Laszewski, G., Younge, A., He, X., Kunze, M., Tao, J., and Fu, C. (2010). Cloud computing: a perspective study. *New Generation Computing*, *28*(2), 137-146. doi: 10.1007/s00354-008-0081-5

Wahid, A., and Banday, M. (2018). Machine type comparative of leading cloud players based on performance & pricing. *In Proceedings of the International Conference on Advances in Computing, Communications and Informatics (pp. 2364-2368).* Banglore, India: IEEE

Weins, K. (2019). Cloud computing trends: 2018 State of the Cloud Survey | Flexera Blog. Retrieved 29 November 2019, from https://www.flexera.com/blog/cloud/2018/02/cloud-computing-trends-2018-state-of-the-cloud-survey/

Xue, C., and Xin, F. (2016). Benefits and challenges of the adoption of cloud computing in business. *International Journal on Cloud Computing: Services and Architecture*, *6*(6), 01-15. doi: 10.5121/ijccsa.2016.6601

Zhang, Q., Cheng, L., and Boutaba, R. (2010). Cloud computing: state-of-the-art and research challenges. *Journal of Internet Services and Applications*, *1*(1), 7-18. doi: 10.1007/s13174-010-0007-6.

APPENDIX 2

ETHICAL APROVAL DOCUMENT

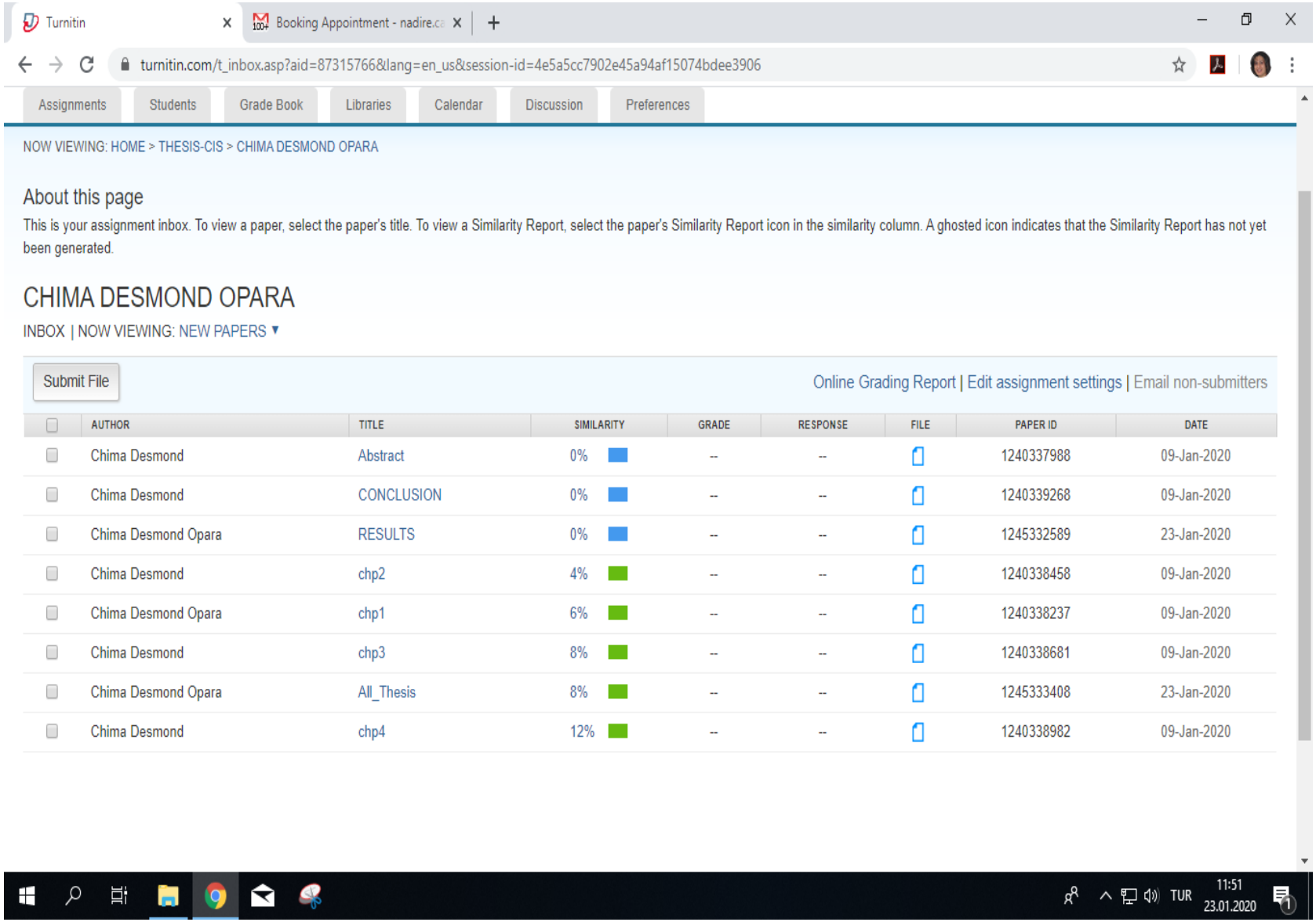
Date: 05/08/2019

To the Graduate School of Applied Sciences

The research study titled "Cloud Computing in Amazon Web Services, Microsoft Windows Azure, Google App Engine and IBM Cloud Platforms: A Comparative Study" has been evaluated. Since the researcher(s) will not collect primary data from humans, animals, plants or earth, this project does not need to go through the ethics committee.

Title: Prof.Dr.
Name Surname: Nadire ÇAVUŞ
Signature:
Role in the Research Project: Supervisor

Title: Assist.Prof.Dr.
Name Surname: Damla KARAGÖZLÜ
Signature:
Role in the Research Project: Co-Supervisor


Turnitin
Booking Appointment - nadire.ca
turnitin.com/t_inbox.asp?aid=87315766&lang=en_us&session-id=4e5a5cc7902e45a94af15074bdee3906
Assignments
Students
Grade Book
Libraries
Calendar
Discussion
Preferences
NOW VIEWING: HOME > THESIS-CIS > CHIMA DESMOND OPARA
About this page
This is your assignment inbox. To view a paper, select the paper's title. To view a Similarity Report, select the paper's Similarity Report icon in the similarity column. A ghosted icon indicates that the Similarity Report has not yet been generated.
CHIMA DESMOND OPARA
INBOX | NOW VIEWING: NEW PAPERS
Submit File
Online Grading Report | Edit assignment settings | Email non-submitters
AUTHOR
TITLE
SIMILARITY
GRADE
RESPONSE
FILE
PAPER ID
DATE
Chima Desmond
Abstract
0%
--
--
1240337988
09-Jan-2020
Chima Desmond
CONCLUSION
0%
--
--
1240339268
09-Jan-2020
Chima Desmond Opara
RESULTS
0%
--
--
1245332589
23-Jan-2020
Chima Desmond
chp2
4%
--
--
1240338458
09-Jan-2020
Chima Desmond Opara
chp1
6%
--
--
1240338237
09-Jan-2020
Chima Desmond
chp3
8%
--
--
1240338681
09-Jan-2020
Chima Desmond Opara
All_Thesis
8%
--
--
1245333408
23-Jan-2020
Chima Desmond
chp4
12%
--
--
1240338982
09-Jan-2020
TUR
11:51
23.01.2020