2017

Performance Evaluation of Hadoop based Big Data Applications with HiBench Benchmarking tool on IaaS Cloud Platforms

Karthika Muthiah Ms.

PERFORMANCE EVALUATION OF HADOOP BASED BIG DATA APPLICATIONS WITH HIBENCH BENCHMARKING TOOL ON IAAS CLOUD PLATFORMS

by

Karthika Muthiah

A thesis submitted to the
School of Computing
in partial fulfillment of the requirements for the degree of

Master of Science in Computer and Information Sciences

UNIVERSITY OF NORTH FLORIDA
SCHOOL OF COMPUTING

December, 2017

The thesis "Performance Evaluation of Hadoop Based Big Data Applications with HiBench Benchmarking Tool on IaaS Cloud Platforms" submitted by Karthika Muthiah in partial fulfillment of the requirements for the degree of Master of Science in Computer and Information Sciences has been

Approved by the thesis committee: Date

______________________________ ____________________
Dr. Sanjay P. Ahuja
Thesis Advisor and Committee Chairperson

______________________________ ____________________
Dr. Zornitza Prodanoff

______________________________ ____________________
Dr. Swapnoneel Roy

Accepted for the School of Computing:

______________________________ ____________________
Dr. Sherif Elfayoumy
Director of the School

Accepted for the College of Computing, Engineering, and Construction:

______________________________ ____________________
Dr. Mark A. Tumeo
Dean of the College

Accepted for the University:

______________________________ ____________________
Dr. John Kantner
Dean of the Graduate School

ACKNOWLEDGEMENT

I would like to take this opportunity to express my deepest gratitude to the people who supported me throughout the duration of this thesis. This thesis would not have been possible without the direction and support of my thesis advisor Dr. Sanjay P. Ahuja. I would also like to thank my committee members, Dr. Zornitza Prodanoff and Dr. Swapnoneel Roy. I would also like to thank Dr. Sherif Elfayoumy, Dr. Mark Tumeo, Dr. William F. Klostermeyer and Mr. Jim Littleton for their feedback and valuable suggestions.

Finally, I would like to thank my parents and my family members for their continuous support and encouragement during the process of achieving this important milestone. This thesis provided me a great learning experience about new and upcoming technologies on Enterprise Cloud computing platforms.

CONTENTS

FIGURES

TABLES

ABSTRACT

Cloud computing is a computing paradigm where large numbers of devices are connected through networks that provide a dynamically scalable infrastructure for applications, data and storage. Currently, many businesses, from small scale to big companies and industries, are changing their operations to utilize cloud services because cloud platforms could increase company's growth through process efficiency and reduction in information technology spending [Coles16]. Companies are relying on cloud platforms like Amazon Web Services, Google Compute Engine, and Microsoft Azure, etc., for their business development.

Due to the emergence of new technologies, devices, and communications, the amount of data produced is growing rapidly every day. Big data is a collection of large dataset, typically hundreds of gigabytes, terabytes or petabytes. Big data storage and the analytics of this huge volume of data are a great challenge for companies and new businesses to handle, which is a primary focus of this paper.

This research was conducted on Amazon's Elastic Compute Cloud (EC2) and Microsoft Azure platforms using the HiBench Hadoop Big Data Benchmark suite [HiBench16]. Processing huge volumes of data is a tedious task that is normally handled through traditional database servers. In contrast, Hadoop is a powerful framework is used to handle applications with big data requirements efficiently by using the MapReduce algorithm to run them on systems with many commodity hardware nodes. Hadoop's distributed file system facilitates rapid storage and data transfer rates of big data among the nodes and remains operational even when a node failure has occurred in a cluster. HiBench is a big data benchmarking tool that is used for evaluating the performance of big data applications whose data are handled and controlled by the Hadoop framework cluster. Hadoop cluster environment was enabled and evaluated on two cloud platforms. A quantitative comparison was performed on Amazon EC2 and Microsoft Azure along with a study of their pricing models. Measures are suggested for future studies and research.

Chapter 1

INTRODUCTION

According to the National Institute of Standards and Technology (NIST), Cloud Computing can be defined as “A model for enabling convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction” [Mell11]. The chief characteristics and features of cloud computing include [Mell11]:

1. *On-Demand and self-service,* where consumers can automatically provision the computing capabilities like server time and network storage without consumers interaction.
2. *Broad network access,* where the computing capabilities are available over the network to the users and can be accessed via heterogeneous client platforms i.e., workstations, servers, laptops, mobiles, and tablets.
3. *Resource Pooling,* where computing resources are shared to serve many users with ease, and supports multi-tenancy within which different physical and virtual resources are dynamically allocated/de-allocated according to user demand.
4. *Rapid Elasticity,* where the allocation of computing resources should be elastic and change quickly as per user needs.

5. *Measured Service,* where cloud systems automatically optimize the resources usage by leveraging metering capability based on computing services offered such as storage, processing active users, bandwidth, etc. Transparency exists between providers and consumers as users can monitor, control and report to the providers about resource usage.

There are three service models provided on the cloud [Mell11]:

1. *Infrastructure-as–a-Service* (IaaS), where providers offer virtualized computing resources over the Internet as a service to the users. The service uses virtualized resources including virtual machines, storage, servers, network, load balancers, etc. In this model, only the infrastructure is available to users.
2. *Platform-as-a-Service* (PaaS), where providers offer the environment, i.e., hardware and software tools necessary for application development, as a service to the users. The environment includes operating systems, program runtime environment, database, web servers, etc. In this model, the infrastructure and platform are available to users.
3. *Software-as–a-Service* (SaaS), where providers offer the software application as a service to the users. Examples of software include salesforce.com, Gmail, Enterprise Resource Planning (ERP), etc. In this model, the infrastructure, platform, and application software are available to users [Mell11].

1.1 Cloud Platforms

1.1.1 Amazon Elastic Compute Cloud (Amazon EC2)

Amazon Elastic Compute Cloud (Amazon EC2) is a web service offered by Amazon Web Service (AWS), which is an Infrastructure as a Service cloud platform. Amazon EC2 offers a scalable computing capacity, allows launching as many virtual servers as possible, and enables the configuration of security, networks, and storage. Each of these can be scaled up or down in the cloud as per customer needs. Amazon EC2 has pre-configured templates of instances called Amazon Machine Images (AMIs) that can be used to create new instances which contain the necessary components for a server, such as the operating system and other software. Secured access to instances is provided with the help of key pairs. The newly launched Amazon EC2 instances using AMI are created from an Amazon EBS (Elastic Block Store) snapshot, and the instance's data are permanently stored in an Amazon EBS volume. The basic structure of Amazon Web Service EC2 instance is shown in Figure 1.

Amazon EC2 offers various purchasing options for instances including: (i) On-Demand Instances, which allow consumers to pay hourly, based on their usage with no long-term commitments or upfront payments for the instances; (ii) Reserved Instances, which allow consumers to get a discounted price and lower hourly rates for the instance if they pay an upfront one-time payment and reserve it for one or three year terms; and (iii) Spot Instances, which allow consumers to bid the price they can pay and mention their maximum price they can afford for the instance. The spot price will never go beyond the maximum bid price and changes are based on demand and available supply of resources.

Some of the benefits of using Amazon EC2 services include the general agreement that these services are easy to use and allow application providers and vendors to quickly and securely host their applications [EC216]. They are flexible and enable the selection of an application platform, programming language, operating system, database, and services as needed. They are also cost-effective, as payment is processed on a per use basis, and provide reliable, scalable, and secured global computing infrastructure [EC216].

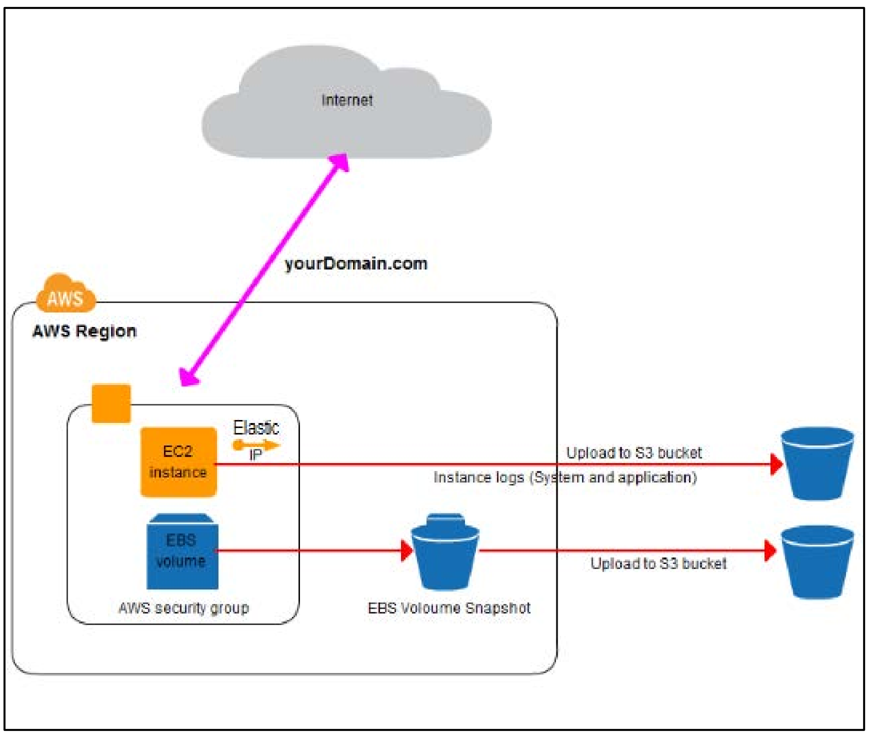


Figure 1: AWS EC2 Structure [EC216]

1.1.2 Microsoft Azure

Microsoft Azure offers a group of integrated cloud services that includes analytics, computing, database, mobile, networking, storage, and web services. Microsoft Azure supports the widest selection of options for operating systems, programming languages, tools, frameworks, databases, and devices [Azure16]. Microsoft Azure supports Windows server, Linux, SQL Server, Oracle and IBM software, and SAP applications. It provides a variety of storage services for different types of data, based on business needs. The storage elements include objects, files, tables, queues, and disks. Microsoft Azure offers network file shares in the cloud by using Server Message Block (SMB) protocol. Table storage is used for NoSQL data. For unstructured types of data, object or blob storage is used. Queue storage is used to store messages efficiently and securely, while premium storage that stores the data on the Solid State Drives (SSDs) is preferred for I/O intensive workloads like high performance and low latency blocks. Figure 2 shows the basic structure of Microsoft Azure's virtual network system along with its load balancing and secured access capability provided to its remote users.

Features like integrated tools, pre-built templates and additional managed services that are available as options make the process of building and managing the enterprise, web, mobile, and Internet of Things applications much easier. Some of the benefits of using Microsoft Azure cloud include [Azure16]:

- Azure cloud is highly scalable which can provision up to petabyte (1024 terabytes) of storage as the business needs grow,

- data can be accessed globally as the storage exists in more than one region,
- storage of data is automatically replicated and maintained as multiple copies so they are highly available and durable even when any unexpected hardware failure occurs.

Microsoft Azure is secure as it offers typical authentication mechanisms, client and server-side data-at-rest encryption, and limits the access rights [AzureStorage17]. Users pay only for the resources consumed. It also supports the execution of enterprise applications [Azure16].

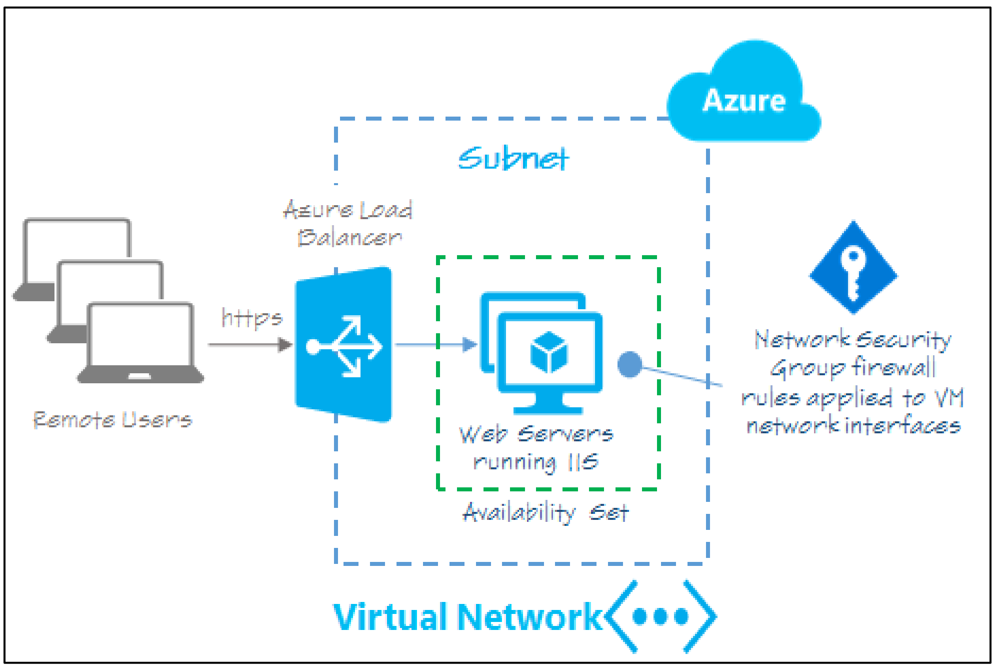


Figure 2: Microsoft Azure Structure [Azure16]

1.2 Big Data Computation

Big Data applications involve the processing and storing of large volumes, typically hundreds of gigabytes, terabytes or petabytes of data and has become critical for cloud providers to provide on-demand computing instances and capacity for such big data storage and computation [BigData16]. The cloud platforms such as Amazon EC2 and Microsoft Azure can support these demands when Hadoop cluster of nodes with master-slave architecture is enabled in the cloud instances. Hadoop's MapReduce algorithm has become the leading programming model for computation of big data applications in cloud computing.

1.2.1 Hadoop

Hadoop is an open source software framework that enables distributed storage and processing of large data sets across clusters of commodity servers, and is a possible solution to big data storage and computation problems. Hadoop is designed to scale up from a single server to thousands of servers and hence can concurrently process large amounts of data to provide faster results. Hadoop runs applications in which data are processed concurrently using the MapReduce algorithm on different CPU nodes. The Hadoop framework is proficient in the development of applications running on clusters of computers that support a master–slave architecture where the master node controls and manages slave nodes [Hadoop16]. Figure 3 shows the Hadoop YARN (Yet Another Resource Negotiator) architecture, which is responsible for providing computational resources (e.g. CPU, memory, etc.) needed for applications execution. The Resource Manager is the ultimate authority that arbitrates resources among all the applications in the system. The Node Manager is associated with per-machine is responsible for containers, monitoring their resource usage and reporting it to the resource manager [YARN16].

The Hadoop framework includes the following modules [Hadoop16]:

- Hadoop Common –libraries and other utilities files required to function by other Hadoop modules.
- Hadoop Distributed File System (HDFS) – a distributed file system that stores data on cluster machines that provide enormous aggregate bandwidth.
- Hadoop YARN – a platform responsible for managing compute and scheduling resources among all applications running in a Hadoop cluster system.
- Hadoop MapReduce – a programming model used for processing of large dataset concurrently.

The following are the benefits of using Hadoop in cloud platforms [Hadoop16]:

- Scalability – It can add servers to, and remove from, the cluster during run time as per need, so Hadoop continues to function without interruption.
- Open Source – Hadoop is an open source software developed using Java language which is platform independent.
- Fault Tolerant – Hadoop libraries are designed to sense and handle failures and do not depend on hardware to provide fault-tolerant capability and high availability.

- Highly Efficient – It is a highly efficient distributed system that distributes data and tasks automatically across machines.

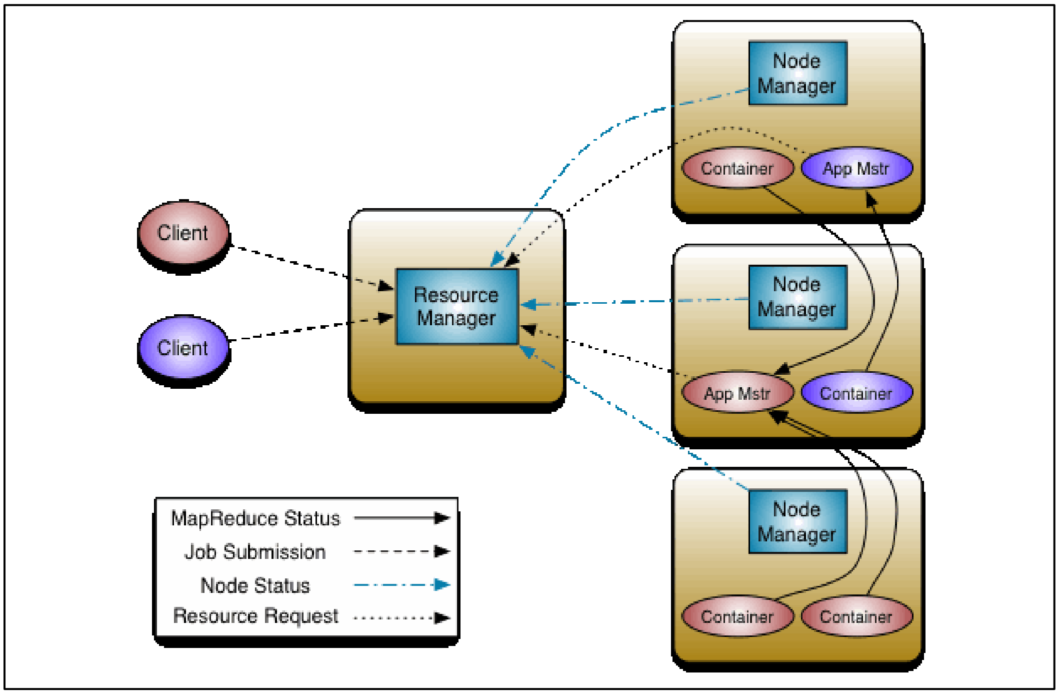


Figure 3: Hadoop YARN Architecture [YARN16]

1.2.2 MapReduce

MapReduce is a job that splits the input dataset into independent chunks that are processed by the map tasks in a parallel manner. The sorted outputs of the maps are fed as input to the reduce tasks. Both the input and output of the MapReduce job are stored in a file system. In the MapReduce file system, the large files are fragmented into smaller blocks of identical size and distributed across the cluster for storage. Each block is stored multiple times in different nodes in order to handle failures in the cluster. The MapReduce framework's data processing is comprised of the Map phase, followed by the

Shuffle phase, which is followed by the Reduce phase. The diagrammatic representation of the MapReduce architecture is shown Figure 4.

In Map phase, the map function is applied to all input, and mappers are launched on all cluster nodes. The blocks of input file data stored in the nodes are processed in parallel. A mapper processes the contents in the block, interpreting each line as a key-value pair. The map function invoked for each of the input pairs creates a subjectively large list with new key-value pairs created from the input pairs.

map(key, value) -> List (key', values')

During the Shuffle phase, the list of key-value pairs created from the Map phase are sorted by their keys locally and assigned to the Reducer according to their keys. The keys that are similar in the key-value pairs are assigned to the matching reducer.

In the Reduce phase, all key-value pairs with the identical key are combined and a sorted list of the values is created. The reduce function is applied on a key and the sorted list of input values gets compressed. It creates a shorter list of values, i.e., the values are aggregated. The reduce function creates a subjectively large list of key-value pairs similar to the map function.

reduce(key, List(values)) -> List(key', value')

Web search serves as a good example in the use of map reduce [Hornung16].

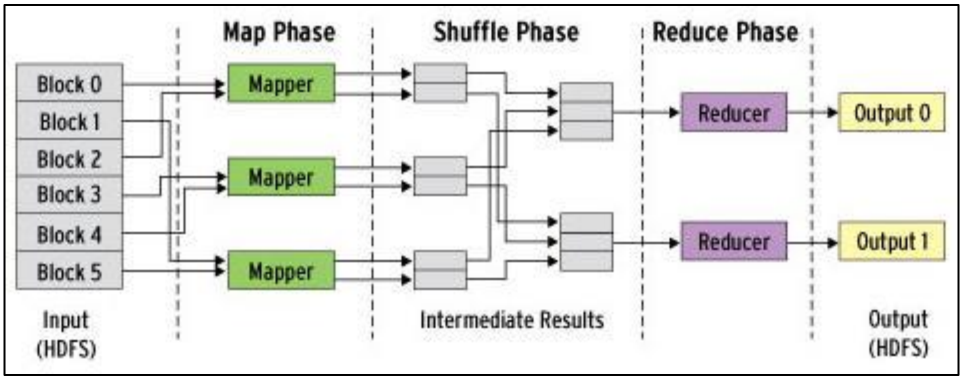


Figure 4: Hadoop MapReduce Architecture [Hornung16]

1.3 Benchmarks

1.3.1 HiBench Benchmarks

HiBench is a more realistic and wide-ranging benchmark suite for the Hadoop framework, which is one of the most common implementations of the MapReduce model. The HiBench suite comprises of a set of Hadoop programs that includes both synthetic micro benchmarks and real-world Hadoop applications characteristic of a broader range of large scale data analysis. These benchmarks are used to intensively evaluate big data based Hadoop applications in terms of speed and throughput [HiBench16].

The categories of benchmarks considered for this research study include Micro benchmarks (WordCount, Sort, and TeraSort) that include more unstructured data, and SQL benchmarks (Aggregation, Join, and Scan) that include structured types of data, Web Search benchmarks (PageRank) that include more semi-structured data, and

Machine Learning benchmarks (Bayes and K-Means) that include data of semi-structured or unstructured type [Huang12].

1.3.1.1 Micro Benchmarks

1) WordCount: This benchmark program reads the input text file and counts how many times each word occurs. These programs are characteristic of a large subset of real-world MapReduce jobs in which a small amount of useful data are extracted from a large dataset. The input data for this workload are generated by executing the preparation script which uses the RandomTextWriter program of the Hadoop distribution. This job abstracts a small quantity of information from a large data source. This process is CPU-bound [Huang12].

2) Sort: This benchmark function sorts the input text file by key. These programs are characteristic of a large subset of real-world MapReduce jobs in which data are transformed from one form to another. The input data for this workload are generated by executing the preparation script which uses the RandomTextWriter program of the Hadoop distribution. This RandomTextWriter uses map or reduce to run a distributed job where there is no interaction between tasks, and each task writes an unsorted large sequence of words. The output of map phase key-value pairs is shuffled and then sorted based on key and again gets reduced based on the key. The sorting of the data is automatically done during the Shuffle and Merge stage of the MapReduce model. This process is I/O-bound [Huang12].

3) TeraSort: This benchmark function also sorts the input text file by key, like the Sort benchmark, but it provides an improved sort where an equal load is distributed among all nodes through the process. The input data for this workload are generated by executing the preparation script which creates 10 billion 100-byte records by default, using the TeraGen program of the Hadoop distribution. TeraGen uses map or reduce to produce data. It splits the desired number of rows by the desired number of tasks and assigns ranges of rows to each map. The map runs the random number generator to correct the value for the first row and generates the subsequent rows. Here, TeraSort samples the input data and uses map or reduce to sort the data into a total order. Hence this process is CPU-bound during the Map stage and I/O-bound during Reduce stage [Huang12].

1.3.1.2 SQL Benchmarks

1) Hive Aggregation, Hive Join, and Hive Scan: The Hive performance benchmarks characterize an important use of MapReduce in On-Line Analytical Processing (OLAP) queries [Hive17]. These benchmarks are intended to model complex analytical queries over structured tables. Hive Aggregation computes the total of each group over a single read-only table, whereas Hive Join computes both the average and total of each group by joining 2 different tables. Hive Scan performs a scan of the tables. The input of this workload is automatically generated web data having hyperlinks that follow Zipfian distribution [ZipFian17]. The data source is created by executing the preparation script that creates 2 tables:

UserVisits and UserRankings tables. After the data source has been created, hive requests perform a Scan, a Join and an Aggregation. These tests are I/O-bound [Huang12].

1.3.1.3 Web Search Benchmarks

1) PageRank: These programs are characteristic of one of the most important uses of MapReduce in large-scale search indexing systems. This workload is an implementation of the PageRank algorithm, a link analysis algorithm which is widely used in web search engines. It calculates the rank i.e., a numerical weight of web pages, based on the number of reference links. This workload comprises of series of Hadoop jobs, in which several jobs are iterated until the coverage condition is satisfied. The Wikipedia page-to-page link database was used as the input data of this workload. The data source is created from web based data whose hyperlinks follow Zipfian distribution [ZipFian17]. This process is CPU-bound [Huang12].

1.3.1.4 Machine Learning Benchmarks

1) Bayesian Classification: These programs characterize an important use of MapReduce in large-scale machine learning. This workload implements Naive Bayesian, a classification algorithm for knowledge discovery and data mining [Bayes17]. This is comprised of a series of 4 Hadoop jobs: extract terms from the

input webpage text, calculate the frequency for each term, and calculate the weighting, and the normalization. The input data are taken from a subset of a Wikipedia dump file which is fragmented using WikipediaXmlSplitter, and then organized into text samples using WikipediaDatasetCreator of Mahout [Mahout17]. These samples are spread into several files as input. This workload uses routinely generated documents containing the words that trail Zipfian distribution [ZipFian17]. The dictionary used for text creation is from the default file /usr/share/dict/linux.words in linux. This process is I/O-bound with high CPU utilization during the Map stage [Huang12].

2) K-Means Clustering: This workload implements K-Means, a very popular clustering algorithm for knowledge discovery and data mining [KMeans17]. The input to this benchmark is a sample set, and each sample is represented as a numerical d-dimensional vector. In this workload, the centroid of each cluster is first computed by executing the Hadoop job iteratively until the number of iterations reaches its determined limit. Then the clustering job is run, which allots each sample to a cluster. A random data generator using statistic distribution is used to produce the workload input. The input dataset is generated by GenKMeansDataset based on Uniform and Gaussian distribution for this benchmark. This process is CPU-bound during iteration and I/O-bound during clustering [Huang12].

The categories of HiBench benchmark and metrics used are shown in Table 1.

Benchmarks	**Method**	**Metrics Measured**
Micro	• WordCount • Sort • TeraSort	• Response Time • Throughput
SQL	• Aggregation • Join • Scan	• Response Time • Throughput
Web Search	• Page Ranking	• Response Time • Throughput
Machine Learning	• Bayes • K-Means	• Response Time • Throughput

Table 1: HiBench Benchmark and Metrics

1.4 Research Objectives

This study compares the performance of Hadoop based big data applications on two major public cloud service providers namely, Amazon EC2 and Microsoft Azure. The number of nodes, hardware and software resources, and instance types are varied while evaluating the performance of each cloud. The research was conducted using Micro, SQL, Web Search, and Machine Learning benchmarks from the HiBench big data benchmarking suite of Hadoop. The literature review discusses previous research work in the field of big data computation, and various benchmarks that could be used to assess the performance of big data applications. Existing performance evaluation has mostly been carried out on servers and clusters using Hadoop, but not on public clouds. It is significant that no prior research work is available that compares the performance between Amazon EC2 cloud and Microsoft Azure IaaS public cloud services using the HiBench benchmark.

Chapter 2

LITERATURE REVIEW

Currently, there is no set of benchmarks available for assessing the performance of big data applications on cloud platforms like Amazon EC2 and Microsoft Azure. There are, however, benchmarks available for big data based applications computation but they have been executed only on servers and Hadoop cluster nodes. There do exist certain studies that assessed cloud performance in Amazon EC2 IaaS cloud platform which are discussed below.

2.1 Studies using Big Data Benchmarks

Han et al. in 'On Big Data Benchmarking' discuss the vital requirements, challenges and tests in developing big data benchmarks and their execution [Han14]. These are relevant when considering the 4V (Volume, Velocity, Variety, and Veracity) properties, generating workloads and test execution in big data systems. Methodologies like Layer design, Data generation, and Test generation are designed to address these requirements challenges. Big data benchmarks like HiBench, GridMix, PigMix, YCSB, etc., are reviewed and compared [HiBench16, GridMix13, PigMix13, YCSB10]. This paper compared existing benchmarks based that are relevant to big data generation and benchmarking.

According to the authors, big data benchmarks like HiBench, GridMix, and PigMix were developed to test the performance of MapReduce Hadoop systems. This is a software framework to process vast amounts of data in parallel. Big data systems have been developed to manage and process big data efficiently, and these have given growth to various new requirements for developing a new group of big data benchmarks.

Huang et al. in 'The HiBench Benchmark Suite: Characterization of the MapReduce-Based Data Analysis' discussed the most prominent map reduce model used in large-scale data analysis in cloud [Huang10]. The authors introduced a new, representative and wide-ranging benchmark suite for Hadoop called HiBench, which is comprised of set of Hadoop programs that include synthetic micro-benchmarks and real-world applications. Using HiBench, the Hadoop framework evaluates various characteristics such as, speed, throughput, bandwidth, system resource consumption, and data access patterns. The characterization of Hadoop workload using four slaves in a Hadoop cluster inferred that such workload has very heavy disk and network I/O unless the output size is small. The best performance is attained by accurately measuring the input data and properly allocating memory buffers to prevent memory spilling in the data. The authors concluded that the HiBench Suite is essential to assess and characterize Hadoop, because the workloads not only characterize a broad range for data analysis, but also exhibit varied performances in terms of data access patterns and resource consumption. This paper is relevant to this research because it used HiBench Benchmark Suite in its experiments to evaluate performance and the same Benchmark suite is used in this research as well.

2.2 Studies on performance analysis in Cloud Computing

Villalpando et al. in 'Performance Analysis Model for Big Data Applications in Cloud Computing' discuss that there are chances that some anomalies and defects may exist in cloud platforms which can affect the performance of big data applications on these platforms [Bautista14]. The paper proposed a performance analysis model for big data applications that integrates software quality concepts which fills the gap that exists between quantitative representation of quality concepts of software and the measurement of big data applications performance. The performance measurement framework for cloud computing is based on a scheme where the performance of a system is analyzed using responsiveness, productivity and utilization sub concepts. The likely outcomes that affects system performance are speed, reliability and availability. The authors concluded that performance analysis model based on measurement framework for cloud computing has been validated by researchers and practitioners and this framework defines the elements that are essential to measure the performance of software quality in cloud computing systems. MapReduce model based applications includes time behavior and resource utilization as the primary factors to be evaluated in determining the performance of cloud computing platforms. These measures are taken into account while improvising the performance of applications. This paper shows how performance analysis results are helpful in detecting the cause of degradation of applications and cloud.

Zheng et al. in 'Real Time Big Data Processing Framework: Challenges and Solutions' discuss the issues that exist in big data processing. In order to address processing issues and improve performance, an architecture is proposed that meets the real-time processing requirements in big data systems [Zheng15]. The integration of real time big data has complex requirements in data collection, data analysis, and data security aspects. The two processing modes of big data are stream and batch processing. In stream processing the data value reduces as it is real-time. In batch processing data are stored first and processed later, either online or offline. MapReduce model is the most representative of the batch processing method. The authors concluded that real time data processing is a huge challenge as it involves massive real-time processing of a large data frame and processing compared to static data. This paper discusses batch and stream processing of big data. This research performed with the help of HiBench benchmark suite, which is a Hadoop based big data framework, that uses MapReduce model, and can process both batch and streaming workloads.

2.3 Studies on EC2 services using open source benchmarks

Hwang et al. in 'Cloud Performance Modeling with Benchmark Evaluation of Elastic Scaling Strategies' evaluated various service clouds, and tested the real-life benchmark programs on Infrastructure as a Service cloud platforms over scaling-out and scaling-up workloads [Hwang14]. Three scaling approaches, scale-up approach, scale-out approach, and auto-scaling approach, were evaluated based on their relative performance, and they found that scaling-out is more often practiced than scaling-up and auto-scaling approaches. The open-source benchmarks namely: YCSB from CloudSuite, HiBench, BenchCloud at USC, and TPC-W were tested and measured for speed, throughput, HDFS bandwidth, and resource utilization metrics on the Amazon IaaS EC2 cloud [YCSB10, HiBench16, BenchCloud14, TPC-W13]. In order to satisfy production services, it becomes important to make the choice of scale-up or scale-out solutions through the workload patterns and resources utilization costs. The workload patterns comprise of large scale data processing and data analytics, web search and service. Evaluating the experimental results, the authors concluded that higher efficiency promotes productivity. This paper suggests that big data analytics can be benchmarked to evaluate performance using metrics in different clouds. Here, the performance of one cloud platform, Amazon EC2, is evaluated using different big data benchmarks. This paper is relevant as it evaluates the performance of a public cloud provider for big data analytics.

As discussed above, there are various available benchmarks that compare the performance of Amazon EC2 IaaS cloud service using different open source big data processing benchmarks, processing of big data is a big challenge and it becomes essential to have knowledge on performance analysis among different public IaaS cloud servicers as this massive workloads can degrade cloud performance. But, there are no studies on benchmarks that evaluate the performance of Amazon EC2 versus Microsoft Azure for big data applications using Hadoop. That is the focus of this research.

Chapter 3

RESEARCH METHODOLOGY

This study assessed the performance of two public IaaS cloud platforms, Amazon EC2 and Microsoft Azure, for big data based application analysis using Hadoop. The study used HiBench benchmark, a big data benchmarking suite, to assess the performance of big data frameworks in terms of speed and throughput for MapReduce, using the following categories of workloads: Micro Benchmarks (WordCount, Sort, and TeraSort), SQL Benchmarks (Aggregation, Join, and Scan), Web Search benchmark (Page Rank), and Machine Learning Benchmarks (Bayesian classification, and K-Means clustering).

After the successful creation of instances in Amazon EC2 and Microsoft Azure cloud platforms, the Hadoop framework was installed in each node, and a cluster environment was configured through which the Master node was able to communicate with its slave nodes. The HiBench benchmark was also installed and configured in all nodes.

The test procedure was started by executing Micro Benchmarks, which is comprised of WordCount, Sort, and TeraSort benchmarks, on the Amazon EC2 cloud platform using different size dataset {1GB; 100GB; and 1,000GB}, and also by varying the number of nodes from 1 to 5 for each dataset. Response time and throughput metrics were measured in each test run of varying nodes and dataset size. The SQL Benchmarks, consisting of Aggregation, Join, and Scan benchmarks, were executed on Amazon EC2 cloud platform with changing dataset of {(uservisits: 1,000,000; pages: 120,000), (uservisits: 10,000,000; pages: 1,200,000), and (uservisits: 100,000,000; pages: 12,000,000)}, and by varying the number of nodes from one to five for each of the dataset. Response time and throughput metrics were measured in each test run of various nodes and dataset sizes. The Web Search Benchmark i.e., PageRank benchmark, was executed on Amazon EC2 cloud platform for different dataset of {(pages: 500,000), (pages: 1,000,000), and (pages: 10,000,000)}, and by varying the number of nodes from one to five for each dataset. Response time and throughput metrics were measured in each test run of varying number of nodes and dataset sizes. The Machine Learning Benchmarks, that consist of Bayesian Classification and K-Means Clustering benchmarks, were run on Amazon EC2 cloud platform for different dataset of Bayes for {(pages: 500,000), (pages: 1,000,000), and (pages: 10,000,000)}, and K-Means for {(# of samples: 20,000,000; samples/file: 4,000,000), (# of samples: 80,000,000; samples/file: 6,000,000), (# of samples: 100,000,000; samples/file: 8,000,000)}, and by varying the number of nodes from one to five for each dataset. Response time and throughput metrics were measured in each test run of varying nodes and dataset sizes.

A similar test procedure was carried out on Microsoft Azure cloud platform with HiBench benchmarks. The average response time and throughput values were tabulated and a graph was plotted to evaluate the workload performance in cloud. The test run executed in both Amazon EC2 and Microsoft Azure cloud platforms using HiBench benchmark was performed for one trial. Conclusions for the experiment were derived by relating the performance of Amazon EC2 and Microsoft Azure cloud platforms by their test results.

Chapter 4

TESTBED SETUP

4.1 Creating Instance on Amazon EC2 Cloud Platform

Amazon EC2 cloud platform allows its users to launch as many virtual instances as they need, configure security and networking, and manage storage. In order to use the service provided by Amazon EC2 cloud platform the user must first create an AWS account, and sign-into the AWS console using the account ID. The instances launched will be Amazon EBS backed instances i.e., the root volume is EBS volume and the user can select any availability zone. AWS uses public-key cryptography to protect the login information of the instances. Amazon EC2 provides a wide variety of instances types with varying combinations of CPU, memory, disk, and networking capacity, which provides flexibility in selecting the appropriate mix of resources for the applications. The instance used in this study was a storage optimized instance from the I2 – High I/O Instances family i2.2x large instance EC2 model. This model provides high storage, fast SSD-backed instance storage enhanced for very high random I/O performance, and high IOPS [EC2Type16].

A comprehensive explanation of creating instance on Amazon EC2 cloud platform and how to access the instance is presented in Appendix A.

4.2 Creating Instance on Microsoft Azure Cloud Platform

The Microsoft Azure Cloud Platform provides its users with full control over creation, configuration, and managing of virtual machines for their applications. In order to create virtual machines in Azure cloud, the user should first create an Azure account, sign-into the Azure portal, and create an Azure subscription. The users create VMs by choosing the appropriate image list, resource manager as the deployment model, authenticate VM using an SSH public key, choose VM size, storage, and network. Azure VMs can store virtual hard disks on Azure Standard Storage devices which are Hard Disk Drives (HDD) that provide high performance and low latency I/O processes for more difficult workloads. This study used a memory optimized G3 instance type VM, which comes under standard tier VMs – G series. The G series VMs provide local storage space on Solid State Devices disks to execute very large memory and I/O processor concentrated workloads [AzureType16].

A comprehensive explanation of creating instance on Microsoft Azure cloud platform and how to access the instance is presented in Appendix B.

4.3 Hadoop setup

Hadoop is a software framework and open source for storing and computing of extremely big dataset in a distributed cluster environment. Using Hadoop, it is possible to execute applications on systems with hundreds and thousands of commodity nodes to handle hundreds and thousands of terabytes of data. The application is broken down into fragments or blocks and can be run on any nodes in the cluster setup. Hadoop is supported in both Linux and Windows operating systems.

4.3.1 Prerequisites

There are some prerequisite software's need to be installed before Hadoop. A comprehensive explanation of installing these prerequisite software's are presented in Appendix C.

4.3.2 Hadoop Installation

After the pre-requisite software is installed, then Hadoop is installed and the necessary configurations are to be done. A comprehensive explanation of installing Hadoop and making the necessary configuration changes are presented in Appendix D.

4.3.3 Creating cluster setup in Hadoop

Hadoop Cluster is installed by unpacking the software on all the nodes in the cluster. Either one or more machines in the cluster can be designated as the master node(s) in which the name node and resource manager daemons will be running. The remaining machines in the cluster are called slave nodes in which both data node and node manager will be running. To configure the Hadoop cluster, the environment in which Hadoop daemons execute and configuration parameters of Hadoop daemons are necessary. Hadoop configuration files are located in <$HADOOP_HOME>/etc/hadoop directory.

Hadoop has 7 major configuration files that need to be configured before starting the Hadoop Cluster.

```
$sudo vi /$HADOOP_HOME/etc/hadoop/hadoop-env.sh
$sudo vi /$HADOOP_HOME/etc/hadoop/yarn-env.sh
$sudo vi /$HADOOP_HOME/etc/hadoop/core-site.xml
$sudo vi /$HADOOP_HOME/etc/hadoop/hdfs-site.xml
$sudo vi /$HADOOP_HOME/etc/hadoop/mapred-site.xml
$sudo vi /$HADOOP_HOME/etc/hadoop/yarn-site.xml
$sudo vi /$HADOOP_HOME/etc/hadoop/slaves
```

A comprehensive explanation of the above files and their configurations that are performed in Amazon EC2 and Microsoft Azure cloud service is presented in Appendix D.

The Hadoop framework is comprised of two main layers namely HDFS layer, which is the Hadoop Distributed File System consisting of Name node and Data nodes of the cluster and Map Reduce Layer, which is the Execution Engine consisting of Resource Manager and Node Managers of the cluster [Noll11]. The overview of multi-node cluster in Hadoop is shown in Figure 5. While starting the Hadoop cluster, the HDFS layer is started first, and then the Map Reduce layer can be started.

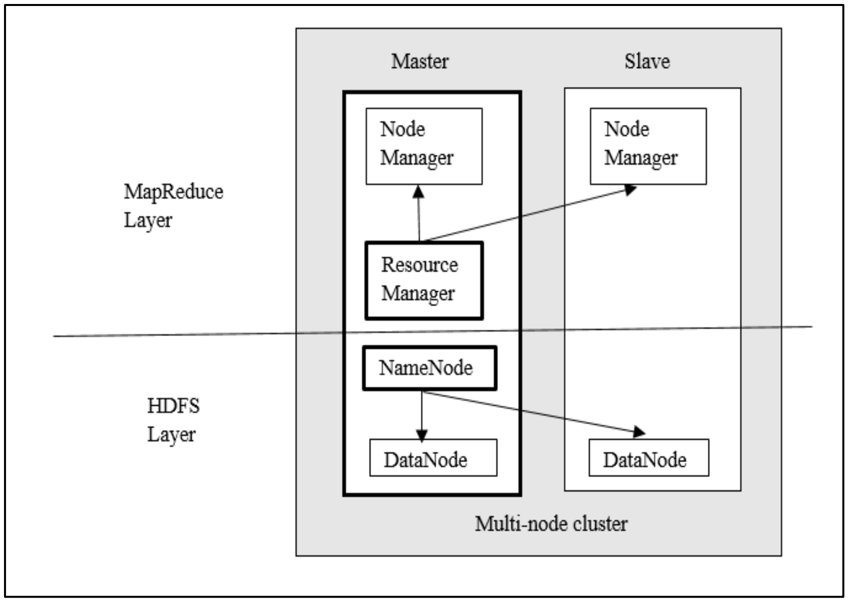


Figure 5: Overview of multi-node cluster [Noll11].

A complete picture on how to start and stop the Hadoop Cluster is detailed in Appendix E.

4.4 HiBench Setup

HiBench is a complete Hadoop based big data benchmark suite developed and introduced by Intel. HiBench Benchmarks are grouped as Micro Benchmarks, SQL Benchmarks, Web Search Benchmarks, and Machine Learning Benchmarks [HiBench16].

4.4.1 HiBench Prerequisite

There are some prerequisite software’s need to be installed for HiBench benchmark. A comprehensive explanation of installing these prerequisite software’s are presented in Appendix F.

4.4.2 HiBench Installation

Once the prerequisite software is installed, there is some configurations need to be setup. A comprehensive explanation of installing HiBench benchmark, making the necessary configuration changes, and thorough picture of executing a HiBench benchmark script is shown in Appendix G.

Chapter 5

HARDWARE AND SOFTWARE SPECIFICATIONS

5.1 Software Specifications

i. Linux flavor Ubuntu14.0 AMI on the workstations.
ii. Java JDK version 1.7.
iii. Python 2.6 or later on Amazon EC2 and Microsoft Azure if it is not installed by default.
iv. Hadoop version 2.2.0 on Amazon EC2 and Microsoft Azure.
v. HiBench version 4.0 on Amazon EC2 and Microsoft Azure cloud.
vi. SSH connection configuration on all the nodes on Amazon EC2 and Microsoft Azure for communication from name node with all its data nodes.
vii. Hadoop cluster creation on Amazon EC2 and Microsoft Azure from their respective dashboards or portals through the web User Interface.

5.2 Hardware Specifications

Configuring hardware for big data application computation benchmarks based on Hadoop is very critical. For Amazon EC2, the I2 Storage Optimized instance type, a high I/O instance was chosen. This specification of I2 instance type was found to very closely resemble the G Series Memory Optimized G3 instance type that had been chosen for

Microsoft Azure. The Amazon I2 instance type features high frequency Intel Xeon E5-2670 v2 (Ivy Bridge) processors which help by providing very fast SSD-backed instance storage that is optimized for very high random I/O performance, and provides high IOPS for low cost. The Azure G3 instance type features the Intel Xeon processor E5 v3 family which helps to provide incomparable computational performance to handle large database workloads, specifically SAP, SQL Server, and Hadoop. Specifications for the instances are provided in Table 2.

Hardware Configuration		
	Amazon EC2	**Microsoft Azure**
Instance Type	i2.2xlarge	G3
Processor	Intel Xeon E5-2670 v2 2.5 GHz	Intel Xeon E5 v3
Memory	61GB	112GB
Storage Drives	1600 GB (2 * 800 GB SSD)	1536 GB
I/O Performance	High / 1000 Mbps	Very High / 500 Mbps

Table 2: Amazon EC2 and Microsoft Azure Hardware Configuration

Chapter 6

RESULTS AND ANALYSIS

The study assessed and compared the performance of Amazon EC2 and Microsoft Azure cloud platforms using the big data based HiBench benchmark suite, which includes the groups: Micro Benchmarks (Sort, WordCount, TeraSort), SQL Benchmarks (Aggregation, Join, Scan), Web Search Benchmark (Page Rank), and Machine Learning Benchmarks (Bayes and K-Means).

For each benchmark, the response time value is in seconds and the throughput value is in megabytes per sec, as measured by incrementing the number of nodes by one from one to five. Graphs for Amazon EC2 and Microsoft Azure cloud platforms were plotted to relate their performance. By changing the dataset size (1GB, 100GB, and 1,000GB) to represent big data applications computation using Hadoop, and by using each benchmark grouped in the HiBench benchmark suite, which includes Micro Benchmarks (Sort, WordCount, TeraSort), SQL Benchmarks (Aggregation, Join, Scan), Web Search Benchmark (Page Rank), and Machine Learning Benchmarks (Bayes, K-Means), the resulting graphs were used to compare the performance of Amazon EC2 and Microsoft Azure cloud platforms. In each of the graphs, the x-axis denotes the number of nodes tested, and the y-axis denotes either the response time value measured in seconds, or throughput value measured in unit megabytes per seconds which were obtained during the tests. The tests were executed for one trial.

6.1 Micro Benchmarks

6.1.1 EC2 and Azure Performance for WordCount

Tables 3 and 4 show the tabulated response time and throughput performance values. Figures 6, 7, and 8 present the graphs plotted for response time and throughput for WordCount benchmark, with varied nodes and data sizes on Amazon EC2 and Microsoft Azure cloud platforms respectively.

Data Size	**1 GB**		**100 GB**		**1,000 GB**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	73.857	68.605	294.892	231.708	3,016.376	3,384.274
2	47.862	42.336	197.763	101.938	1,724.454	1,622.662
3	46.678	39.036	90.083	80.793	1,225.565	1,194.508
4	49.81	38.494	75.963	109.529	968.444	1,074.223
5	37.57	36.544	77.794	61.689	805.737	809.162

Table 3: WordCount: Response Time - EC2 vs. Azure

Data Size	**1 GB**		**100 GB**		**1,000 GB**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	13,898,957	14,963,013	14,951,001	19,027,962	2,458,881	2,353,937
2	21,447,752	24,247,449	22,294,045	43,250,980	4,301,018	4,909,444
3	21,991,727	26,296,800	48,942,960	54,570,933	6,051,829	6,669,215
4	20,609,073	26,667,440	58,040,250	40,253,705	7,656,992	7,415,952
5	27,323,432	28,090,250	56,674,772	71,470,783	9,205,298	9,845,391

Table 4: WordCount: Throughput – EC2 vs. Azure

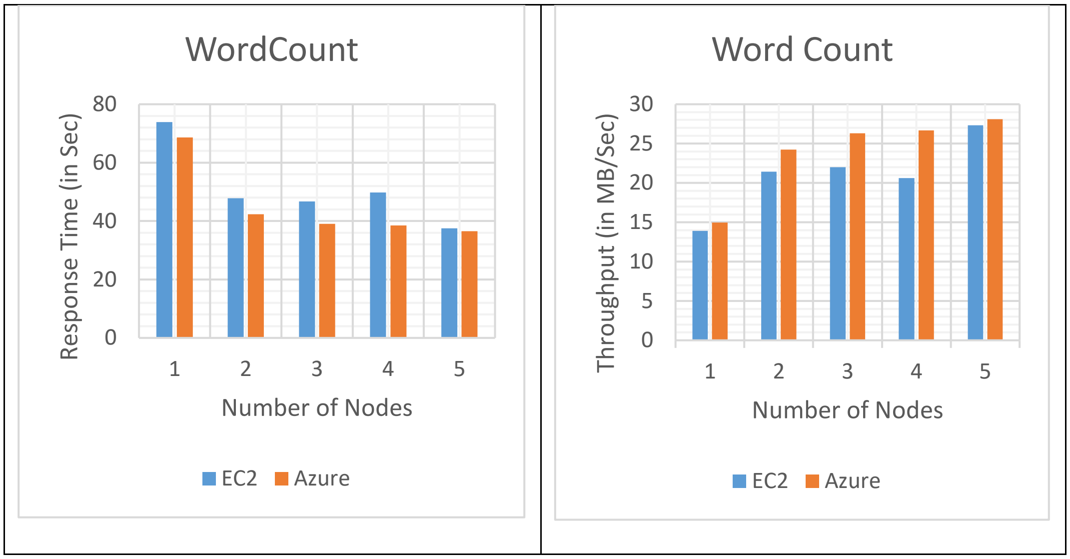


Figure 6: WordCount - EC2 vs. Azure (1GB)

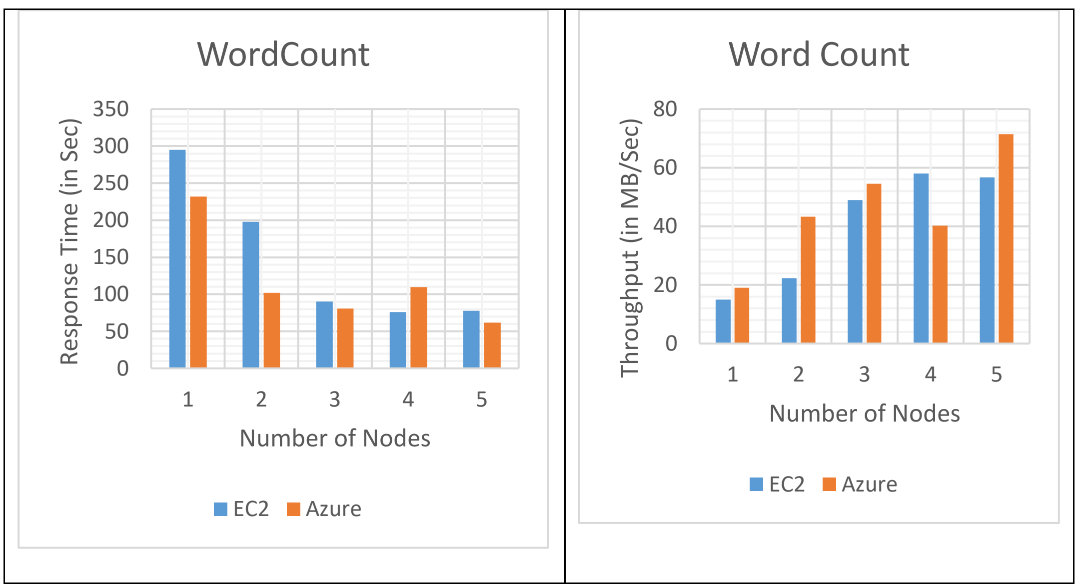


Figure 7: WordCount – EC2 vs. Azure (100GB)

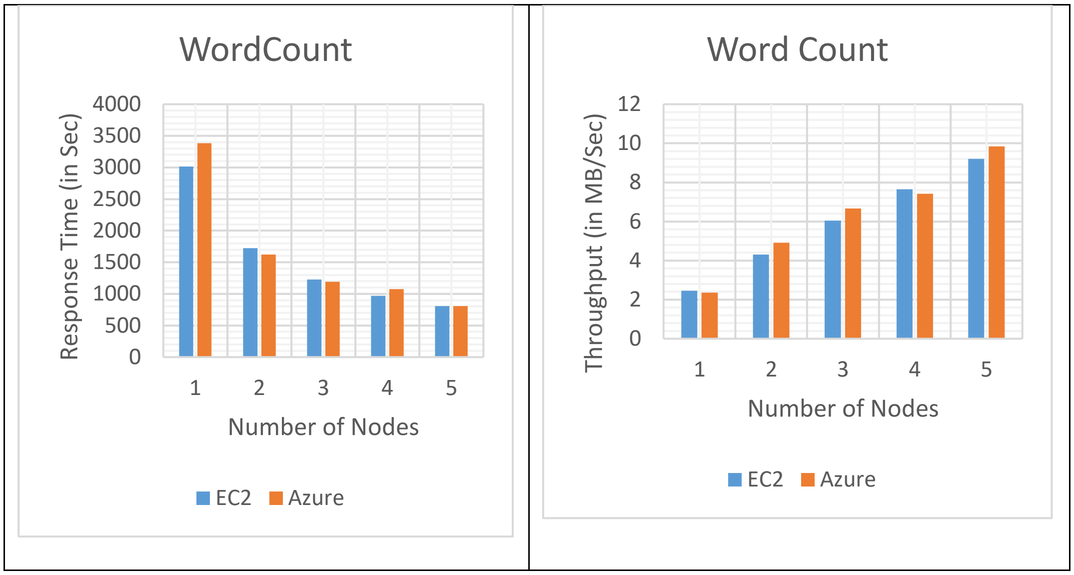


Figure 8: WordCount – EC2 vs. Azure (1,000GB)

Test results from Tables 3 and 4 showing one trial execution values indicate that Microsoft Azure performed better than the Amazon EC2 cloud platform for 1GB data size as the Azure cloud showed better values than EC2. When data sizes were increased to 100GB and 1,000GB Amazon EC2 and Microsoft Azure platforms were found to have similar performance.

Using the graphical results shown in Figures 6, 7, and 8, it can be concluded that Microsoft Azure performed better than Amazon EC2 cloud platform for the smaller data size of 1GB. For larger data sizes of 100GB or 1,000GB, the performance of Amazon EC2 and Microsoft Azure cloud platforms was about the same.

6.1.2 EC2 and Azure Performance for Sort

Tables 5 and 6 show the tabulated performance values for response time and throughput, and Figures 9, 10, and 11 present the graphs plotted for response time and throughput for the Sort benchmark, with varied nodes and data sizes on Amazon EC2 and Microsoft Azure cloud platforms respectively.

Sort – Response Time						
Data Size	**1 GB**		**100 GB**		**1,000 GB**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	36.687	31.481	146.569	117.8	1,665.656	1,785.362
2	28.856	29.573	103.115	67.939	956.111	921.965
3	29.122	23.478	84.009	39.498	719.021	670.769
4	26.908	22.756	81.968	36.532	565.557	556.199
5	25.644	20.453	55.139	36.915	473.28	442.98

Table 5: Sort: Response Time – EC2 vs. Azure

Sort – Throughput						
Data Size	**1 GB**		**100 GB**		**1,000 GB**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	27,980,892	32,608,106	30,081,035	37,427,237	4,452,885	4,154,276
2	35,574,221	34,711,711	42,757,426	64,895,510	7,757,444	8,044,648
3	35,249,531	43,723,330	52,481,786	111,624,526	10,315,373	11,057,312
4	38,149,744	45,110,982	53,788,463	120,687,349	13,114,467	13,335,103
5	40,030,594	50,189,927	79,960,734	119,434,593	15,671,166	16,743,290

Table 6: Sort: Throughput – EC2 vs. Azure

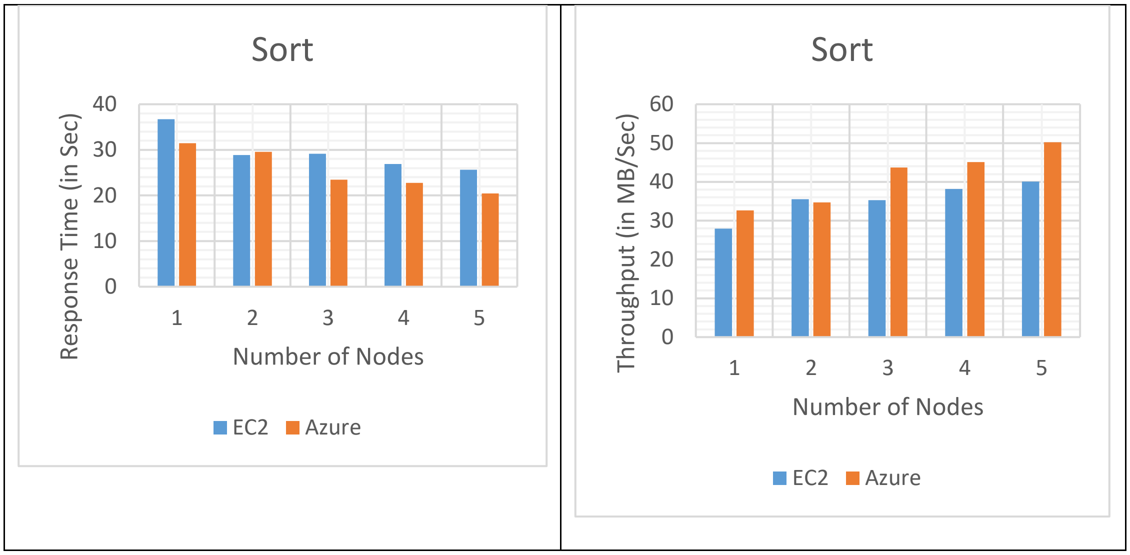


Figure 9: Sort – EC2 vs. Azure (1GB)

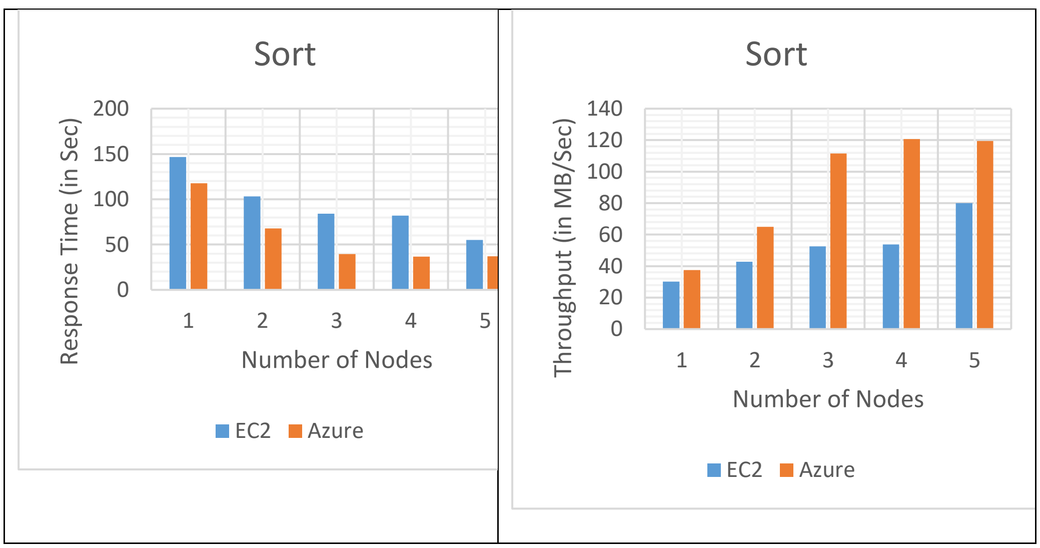


Figure 10: Sort – EC2 vs. Azure (100GB)

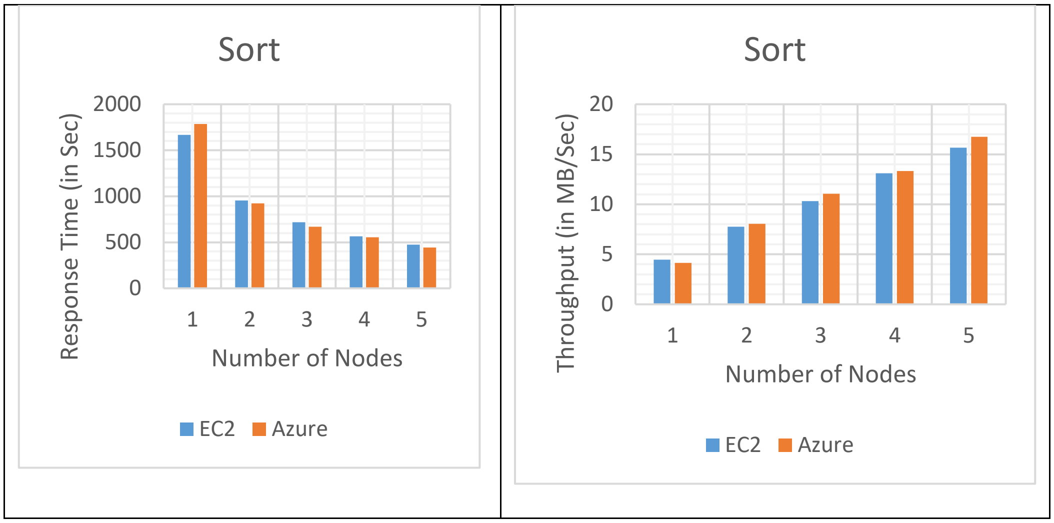


Figure 11: Sort – EC2 vs. Azure (1,000GB)

Test results from Tables 5 and 6 indicate that Microsoft Azure performed better than Amazon EC2 cloud platform for the data sizes of 1GB and 100GB. When data size was increased to 1,000GB, Amazon EC2 and Microsoft Azure cloud platform were found to have similar performance.

The graphical results shown in Figures 9, 10, and 11, illustrate that Microsoft Azure performed better than Amazon EC2 cloud platform for data sizes 1GB, and 100GB, as Azure cloud showed better values than EC2. When the data size was increased to 1,000GB, the difference in performance between Microsoft Azure and Amazon EC2 cloud platform was about the same

6.1.3 EC2 and Azure Performance for TeraSort

Tables 7 and 8 show the tabulated performance values for response time and throughput, and Figures 12, 13, and 14 present the graphs plotted for response time and throughput for the TeraSort benchmark, with varied nodes and data sizes on Amazon EC2 and Microsoft Azure cloud platforms respectively.

Tera Sort – Response Time						
Data Size	**1 GB**		**100 GB**		**1,000 GB**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	44.352	38.739	190.19	184.142	479.58	375.93
2	31.918	30.823	157.068	102.973	248.515	176.499
3	30.213	29.294	82.417	83.036	180.35	113.585
4	30.878	26.789	75.457	81.342	151.424	166.093
5	24.743	27.204	80.071	68.718	143.207	155.545

Table 7: TeraSort: Response Time – EC2 vs. Azure

Tera Sort – Throughput						
Data Size	**1 GB**		**100 GB**		**1,000 GB**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	22,546,897	25,813,779	26,289,499	27,152,958	20,851,578	26,600,696
2	31,330,283	32,443,305	31,833,278	48,556,417	40,239,019	56,657,544
3	33,098,335	34,136,683	60,667,095	60,214,846	55,447,740	88,039,793
4	32,385,517	37,328,754	66,262,904	61,468,859	66,039,729	60,207,233
5	40,415,471	36,759,300	62,444,580	72,761,139	69,828,988	64,290,076

Table 8: TeraSort: Throughput – EC2 vs. Azure

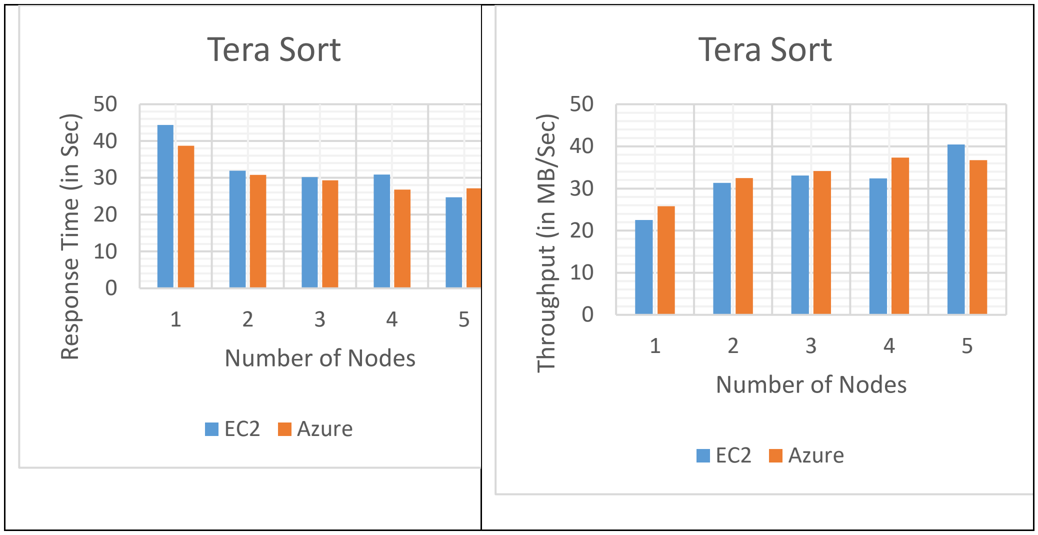


Figure 12: TeraSort – EC2 vs. Azure (1GB)

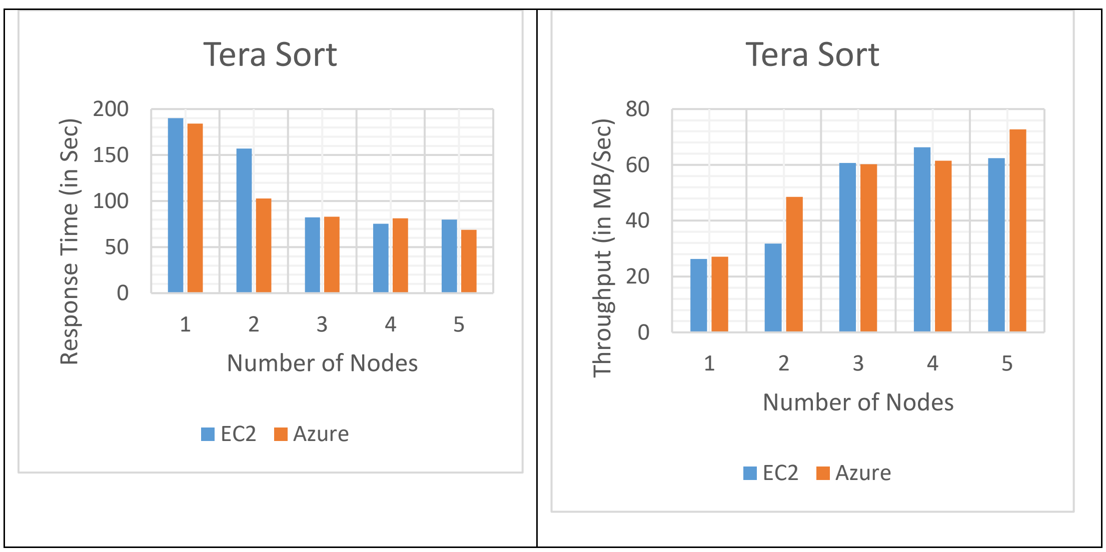


Figure 13: TeraSort – EC2 vs. Azure (100GB)

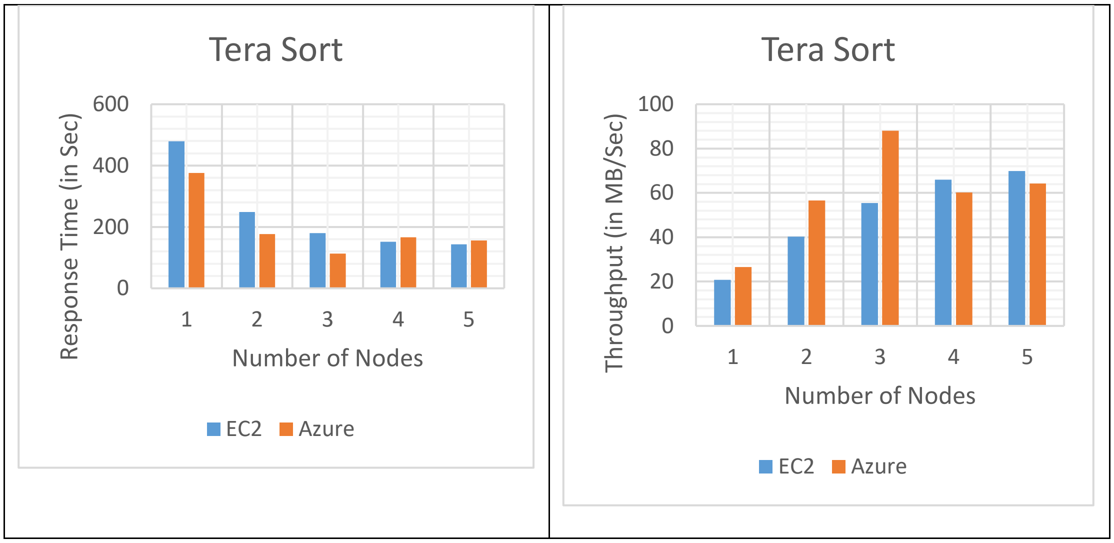


Figure 14: TeraSort – EC2 vs. Azure (1,000GB)

Test results shown in Tables 7 and 8 indicate that the performance of both Amazon EC2 cloud and Microsoft Azure cloud platforms for all the data sizes 1GB, 100GB and 1,000GB was found to be almost equal.

The graphical results shown in Figures 12, 13, and 14 illustrate that both Microsoft Azure and Amazon EC2 cloud platforms performed about the same for all three data sizes (1GB, 100GB, and 1,000GB).

6.2 SQL Benchmarks

6.2.1 EC2 and Azure Performance for Aggregation

Tables 9 and 10 show the tabulated performance values for response time and throughput, and Figures 15, 16, and 17 present the graphs plotted for response time and throughput for the aggregation benchmark, with varied nodes and data sizes on Amazon EC2 and Microsoft Azure cloud platforms respectively.

Aggregation – Response Time						
Data Size	**Uservisits:1,000,000 Pages: 120,000**		**Uservisits:10,000,000 Pages: 1,200,000**		**Uservisits:100,000,000 Pages: 12,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	47.471	38.564	104.162	64.428	402.174	449.942
2	33.335	32.888	50.135	54.298	310.544	316.869
3	32.445	34.596	45.913	40.659	225.432	186.598
4	30.868	31.85	42.538	39.147	172.801	161.46
5	30.647	31.006	41.861	41.523	171.525	121.12

Table 9: Aggregation: Response Time – EC2 vs. Azure

Aggregation – Throughput						
Data Size	**Uservisits:1,000,000 Pages: 120,000**		**Uservisits:10,000,000 Pages: 1,200,000**		**Uservisits:100,000,000 Pages: 12,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	781,957	966,619	3,575,078	5,779,898	9,166,325	8,193,185
2	1,118,245	1,133,444	7,427,691	6,858,213	11,870,968	11,634,013
3	1,148,920	1,077,486	8,110,715	9,158,791	16,352,858	19,756,148
4	1,207,616	1,170,383	8,754,226	9,512,537	21,333,544	22,832,019
5	1,216,324	1,202,241	8,895,804	8,968,217	21,492,247	30,436,408

Table 10: Aggregation: Throughput – EC2 vs. Azure

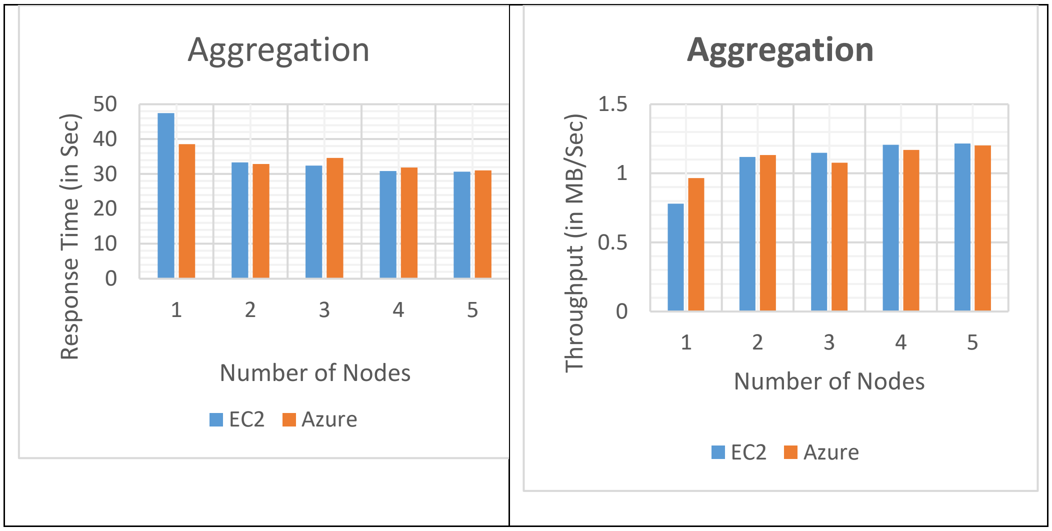


Figure 15: Aggregation – EC2 vs. Azure (120,000 Pages)

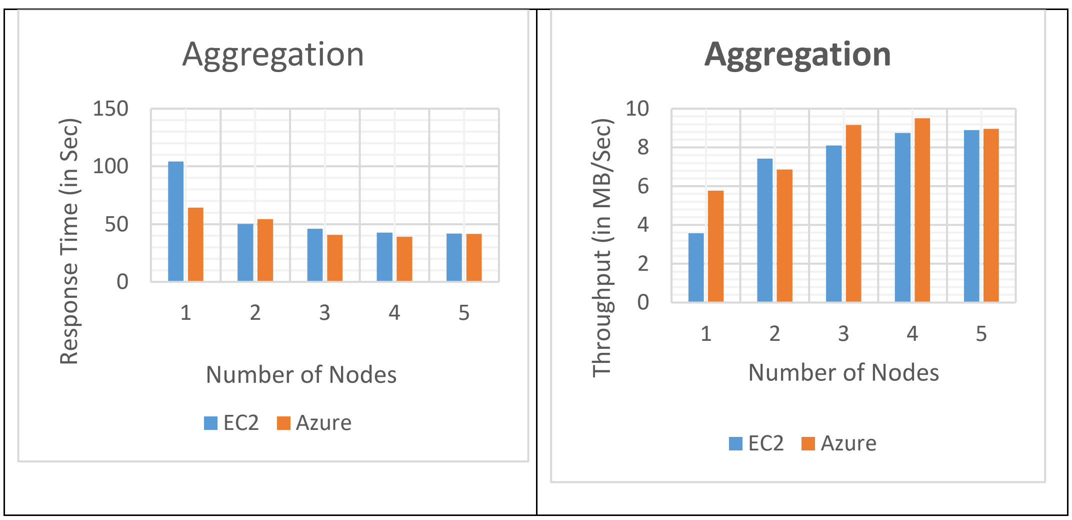


Figure 16: Aggregation – EC2 vs. Azure (1,200,000 Pages)

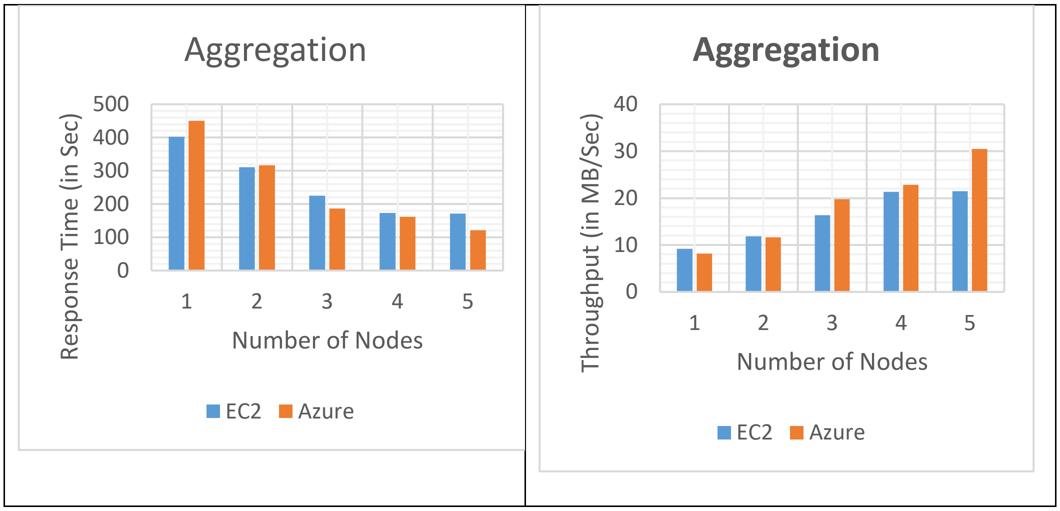


Figure 17: Aggregation – EC2 vs. Azure (12,000,000 Pages)

Test results from Tables 9 and 10 indicate that both Microsoft Azure and Amazon EC2 cloud platforms performed almost equal for all the dataset (user visits: 1,000,000; pages: 120,000), (user visits: 10,000,000; pages: 1,200,000) and (user visits: 100,000,000; pages: 12,000,000).

Using the graphical results as shown in Figures 15, 16, and 17, it can be concluded that the performance of Microsoft Azure and Amazon EC2 cloud platform for dataset (user visits: 1,000,000; pages: 120,000), (user visits: 10,000,000; pages: 1,200,000), and (user visits: 100,000,000; pages: 12,000,000) was found to be the same.

6.2.2 EC2 and Azure Performance for Join

Tables 11 and 12 shows the tabulated performance values for response time and throughput, and Figures 18, 19, and 20 present the graphs plotted for response time and throughput for the Join benchmark, with varied nodes and data sizes on Amazon EC2 and Microsoft Azure cloud platforms respectively.

Join – Response Time						
Data Size	**Uservisits:1,000,000 Pages: 120,000**		**Uservisits:10,000,000 Pages: 1,200,000**		**Uservisits:100,000,000 Pages: 12,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	88.309	78.91	162.682	142.112	451.226	524.538
2	62.316	56.888	97.423	84.572	243.974	312.336
3	63.223	54.894	83.432	75.21	228.679	194.476
4	61.405	53.526	80.261	73.676	191.79	188.388
5	60.443	53.945	79.933	69.892	161.818	149.929

Table 11: Join: Response Time – EC2 vs. Azure

Join – Throughput						
Data Size	**Uservisits:1,000,000 Pages: 120,000**		**Uservisits:10,000,000 Pages: 1,200,000**		**Uservisits:100,000,000 Pages: 12,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	11,328	12,678	61,605	70,522	222,571	191,463
2	16,054	17,586	102,871	118,502	411,641	321,544
3	15,823	18,224	120,122	133,252	439,173	516,412
4	16,292	18,690	124,868	136,028	523,644	533,100
5	16,551	18,545	125,380	143,393	620,634	669,849

Table 12: Join: Throughput – EC2 vs. Azure

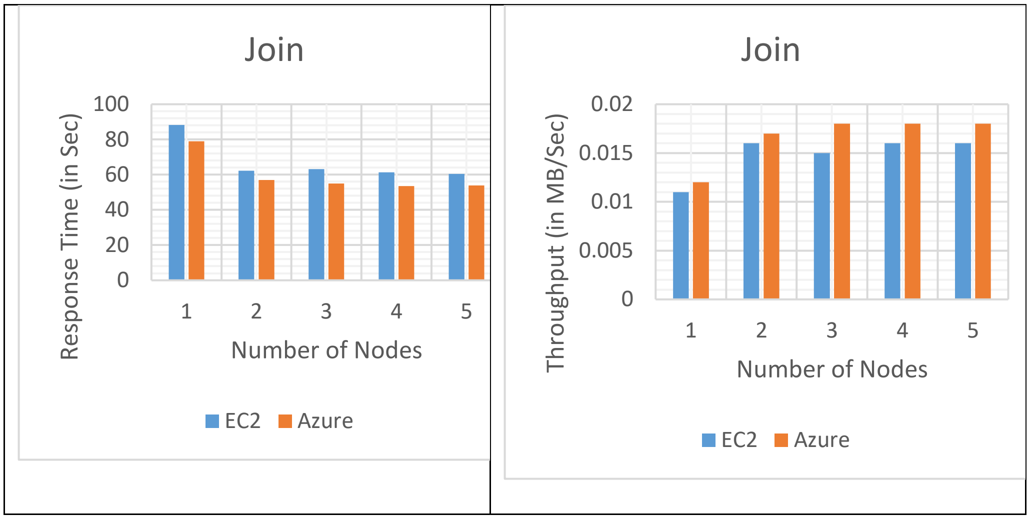


Figure 18: Join – EC2 vs. Azure (120,000 Pages)

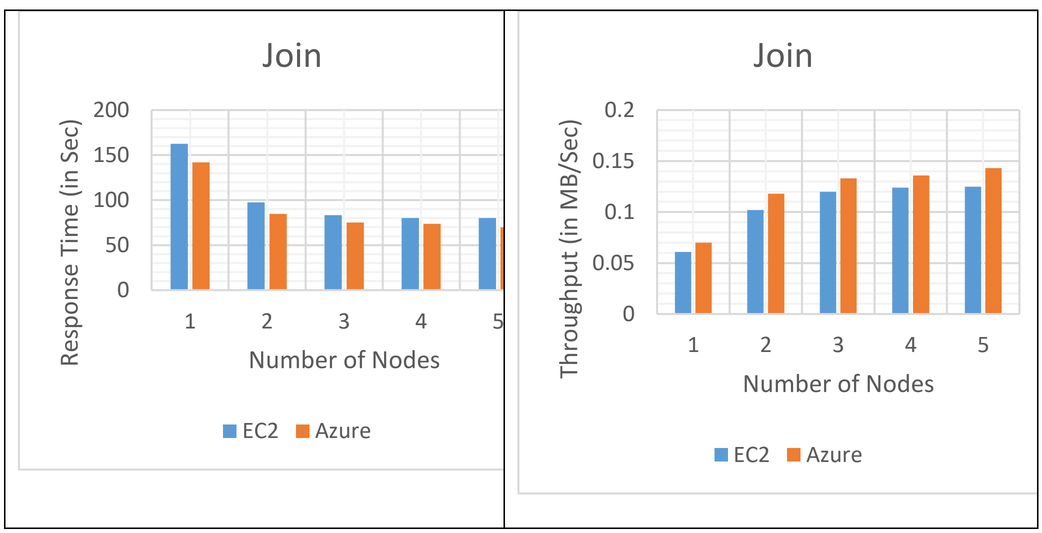


Figure 19: Join – EC2 vs. Azure (1,200,000 Pages)

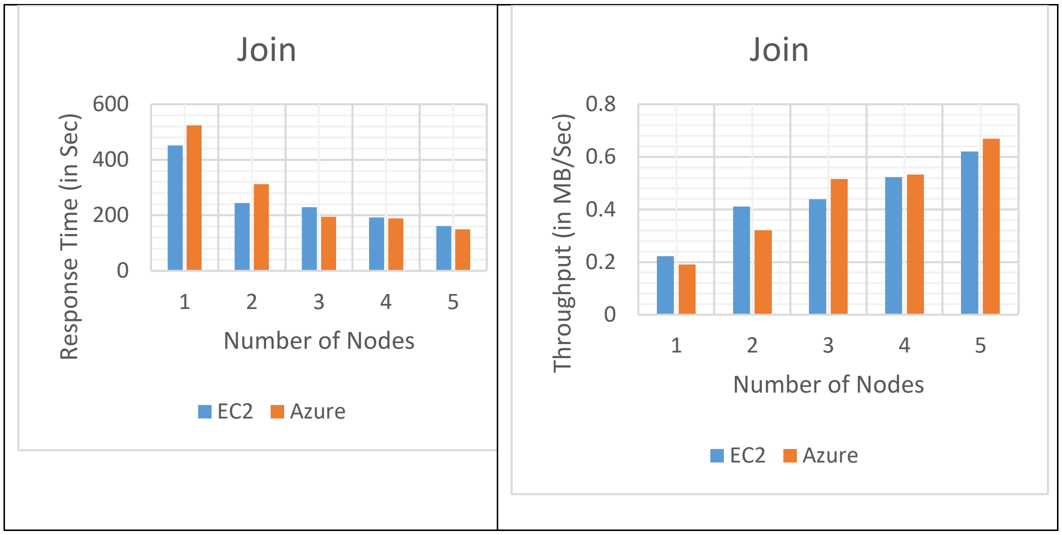


Figure 20: Join – EC2 vs. Azure (12,000,000 Pages)

Test results from Tables 11 and 12 indicate that Microsoft Azure performed better than Amazon EC2 cloud platform as Azure showed better values than EC2 cloud for the dataset (user visits: 1,000,000; pages: 120,000), and (user visits: 10,000,000; pages: 1,200,000). For big dataset (user visits: 100,000,000; pages: 12,000,000), the difference in performance between Amazon EC2 and Microsoft Azure in terms of both response time and throughput metric values does not show noticeable change.

Using the graphical results as shown in Figures 18, 19, and 20, it can be concluded that Microsoft Azure performed better than Amazon EC2 cloud platform, as Azure cloud shows better values than EC2 for dataset (user visits: 1,000,000; pages: 120,000) and (user visits: 10,000,000; pages: 1,200,000). When the big size dataset (user visits: 100,000,000; pages: 12,000,000) was tested the performance of Microsoft Azure and Amazon EC2 cloud was found to be same.

6.2.3 EC2 and Azure Performance for Scan

Tables 13 and 14 show the tabulated performance values for response time and throughput, and Figures 21, 22, and 23 present the graphs plotted for response time and throughput for the Scan benchmark, with varied nodes and data sizes on Amazon EC2 and Microsoft Azure cloud platforms respectively.

Scan – Response Time						
Data Size	**Uservisits:1,000,000 Pages: 120,000**		**Uservisits:10,000,000 Pages: 1,200,000**		**Uservisits:10,000,000 Pages: 12,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	56.003	52.872	66.476	73.026	311.251	398.762
2	41.878	38.747	39.669	40.818	172.453	190.88
3	41.324	38.624	35.657	37.304	132.609	143.825
4	40.969	40.314	37.277	32.73	114.203	115.053
5	40.606	37.545	31.933	28.067	107.856	84.214

Table 13: Scan: Response Time – EC2 vs. Azure

Scan – Throughput						
Data Size	**Uservisits:1,000,000 Pages: 120,000**		**Uservisits:10,000,000 Pages: 1,200,000**		**Uservisits:10,000,000 Pages: 12,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	3,262,600	3,455,806	27,476,379	25,011,910	58,693,454	45,812,694
2	4,363,040	4,715,601	46,044,009	44,747,900	105,932,609	95,706,182
3	4,421,532	4,730,618	51,224,718	48,963,108	137,761,360	127,018,224
4	4,459,845	4,532,306	48,998,572	55,805,676	159,964,240	158,782,440
5	4,499,714	4,866,570	57,198,503	65,077,129	169,377,653	219,386,358

Table 14: Scan: Throughput – EC2 vs. Azure

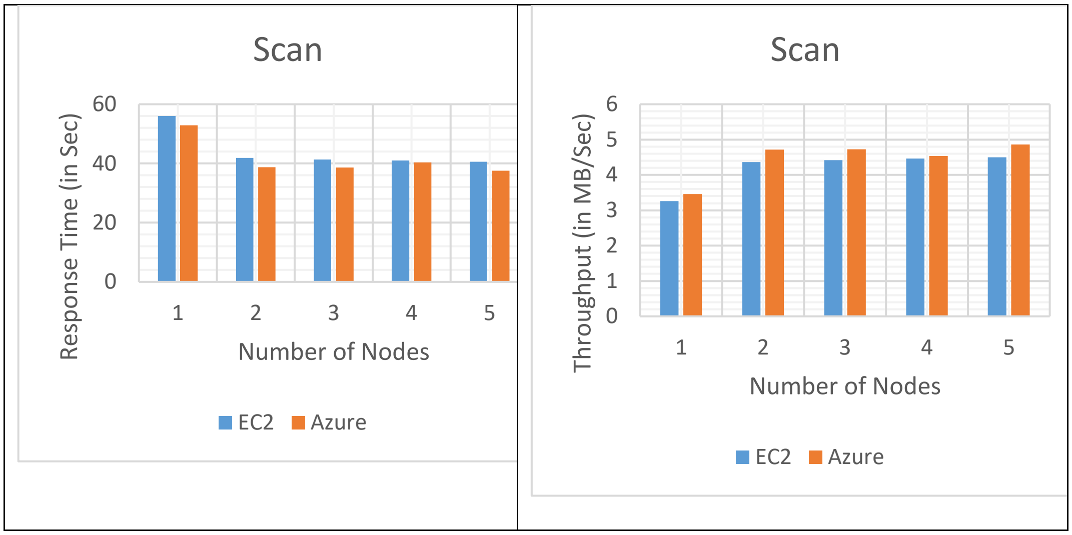


Figure 21: Scan – EC2 vs. Azure (120,000 Pages)

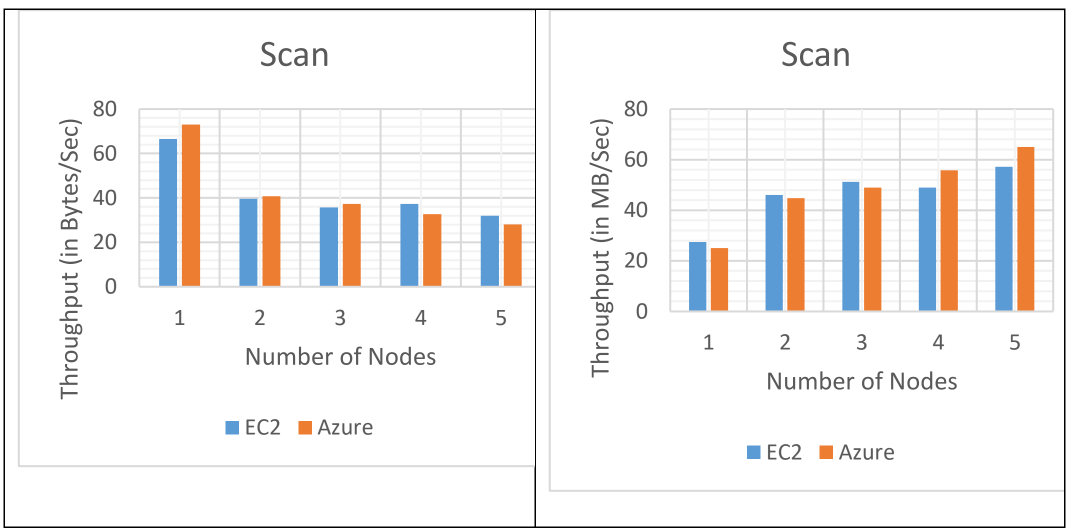
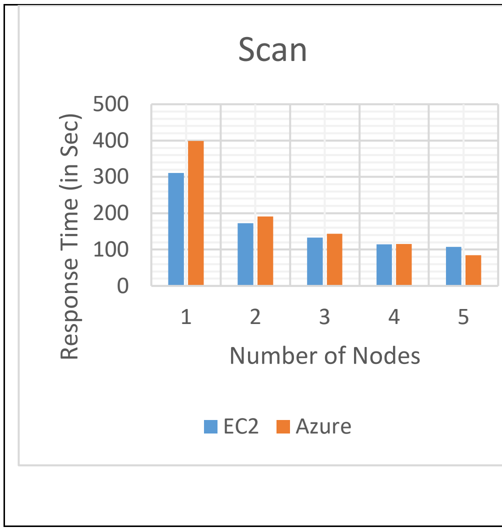


Figure 22: Scan – EC2 vs. Azure (1,200,000 Pages)



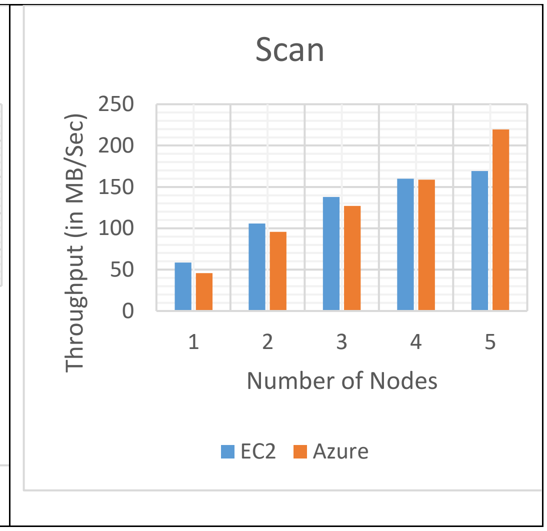


Figure 23: Scan – EC2 vs. Azure (12,000,000 Pages)

Test results from Tables 13 and 14 indicate that Microsoft Azure performed better than Amazon EC2 cloud platform for the dataset (user visits: 1,000,000; pages: 120,000). For larger dataset (user visits: 10,000,000; pages: 1,200,000), and (user visits: 100,000,000; pages: 12,000,000) the performance of Amazon EC2 and Microsoft Azure cloud was equal in terms of both response time and throughput metric values.

Using the graphical results as shown in Figures 21, 22, and 23 it can be concluded that Microsoft Azure achieved better results with better response time and throughput values than Amazon EC2 cloud platform for dataset (user visits: 1,000,000; pages: 120,000). For larger dataset (user visits: 10,000,000; pages: 1,200,000), and (user visits: 100,000,000; pages: 12,000,000) the performance of Microsoft Azure and Amazon EC2 cloud was found to be the same.

6.3 Web Search Benchmarks

6.3.1 EC2 and Azure Performance for PageRank

Tables 15 and 16 show the tabulated performance values for response time and throughput, and Figures 24, 25, and 26 present the graphs plotted for response time and throughput for the PageRank benchmark, with varied nodes and data sizes on Amazon EC2 and Microsoft Azure cloud platforms respectively.

Page Rank – Response Time						
Data Size	**Pages: 500,000**		**Pages: 1,000,000**		**Pages: 10,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	116.985	135.275	192.808	153.139	1,725.18	1,203.226
2	87.783	69.555	120.549	99.541	974.933	586.148
3	83.333	70.522	115.711	96.291	692.839	461.418
4	82.757	66.6	105.426	87.864	551.037	422.2
5	71.754	63.708	96.296	102.348	522.755	439.432

Table 15: PageRank: Response Time – EC2 vs. Azure

Page Rank – Throughput						
Data Size	**Pages: 500,000**		**Pages: 1,000,000**		**Pages: 10,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	2,221,892	1,921,479	2,756,190	3,470,152	2,815,939	4,037,481
2	2,961,030	3,737,015	4,408,295	5,338,661	4,982,907	8,288,013
3	3,100,546	3,685,773	4,592,611	5,518,850	7,011,733	10,528,420
4	3,140,859	3,902,824	5,040,650	6,048,161	8,816,109	11,506,401
5	3,622,489	4,079,991	5,518,564	5,192,242	9,293,077	11,055,186

Table 16: PageRank: Throughput – EC2 vs. Azure

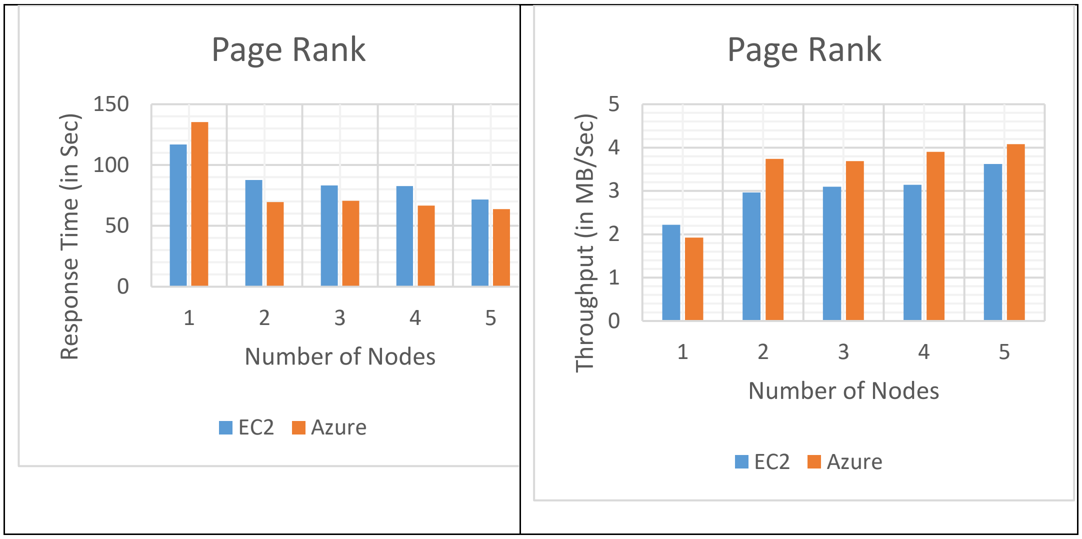


Figure 24: PageRank – EC2 vs. Azure (500,000 Pages)

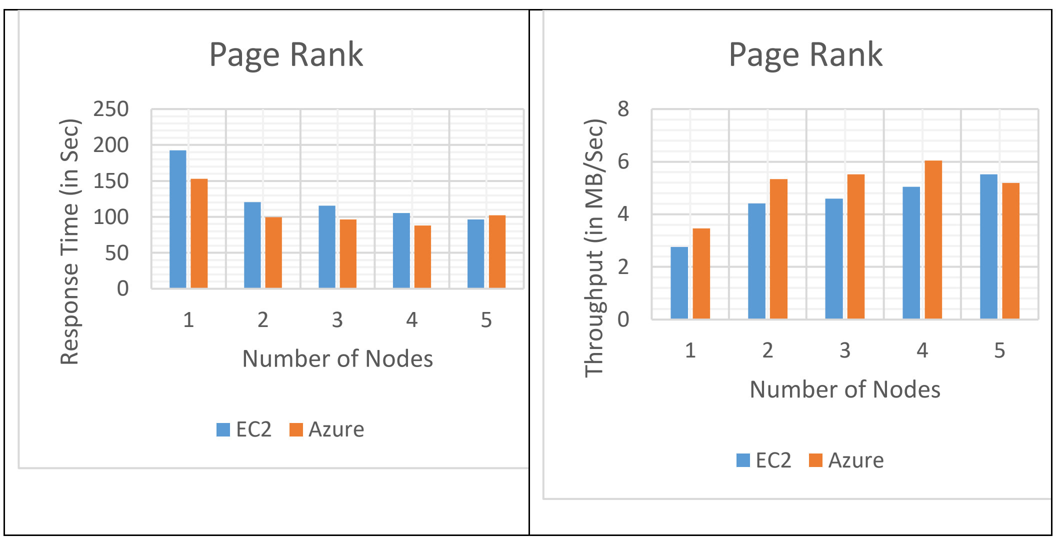


Figure 25: PageRank – EC2 vs. Azure (1,000,000 Pages)

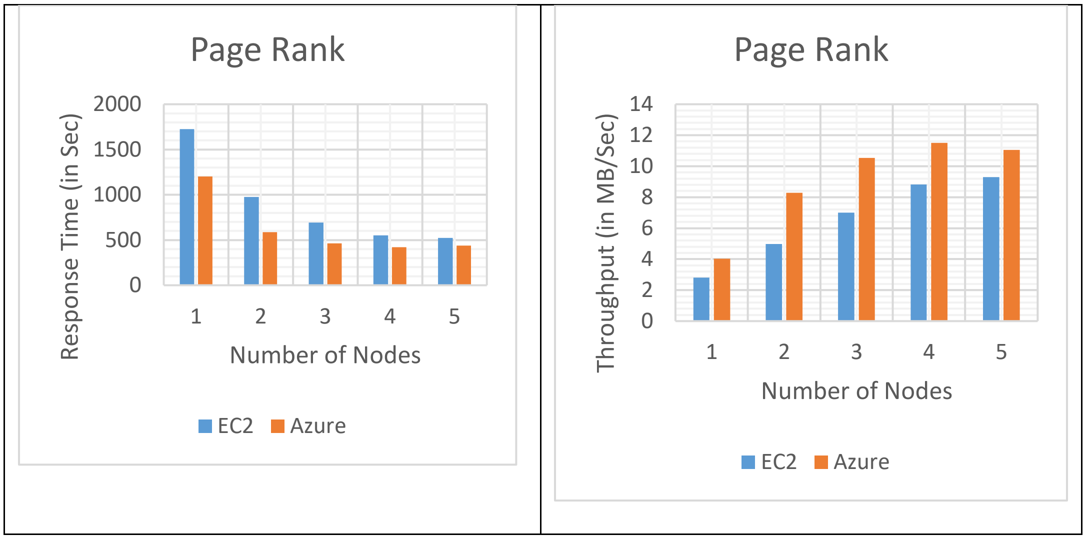


Figure 26: PageRank – EC2 vs. Azure (10,000,000 Pages)

Test results from Tables 15 and 16 indicate that Microsoft Azure performed better than Amazon EC2 cloud platform for larger dataset (pages: 1,000,000), and (pages: 10,000,000) in terms of both response time and throughput metric values. However, for a smaller dataset (pages: 500,000) both clouds performed the same.

Using the graphical results as shown in Figures 24, 25, and 26, it can be concluded that both Microsoft Azure and Amazon EC2 cloud platforms performed about the same for the smaller dataset of (pages: 500,000). For larger dataset (pages: 1,000,000), and (pages: 10,000,000) Microsoft Azure performed better than Amazon EC2 cloud platform as Azure showed better performance values than EC2 cloud.

6.4 Machine Learning Benchmarks

6.4.1 EC2 and Azure Performance for Bayesian Classification

Tables 17 and 18 show the tabulated performance values for response time and throughput, and Figures 27, 28, and 29 present the graphs plotted for response time and throughput for Bayes benchmark, with varied nodes and data sizes on Amazon EC2 and Microsoft Azure cloud platforms respectively.

Bayes – Response Time						
Data Size	**Pages: 100,000**		**Pages: 500,000**		**Pages: 1,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	81.123	72.142	108.332	99.811	149.403	154.619
2	57.442	48.072	75.27	68.356	97.122	96.984
3	51.213	45.32	67.311	62.558	84.755	82.171
4	49.021	43.464	60.354	59.826	74.055	68.16
5	50.016	44.005	63.882	56.098	70.464	57.611

Table 17: Bayes: Response Time – EC2 vs. Azure

Bayes – Throughput						
Data Size	**Pages: 100,000**		**Pages: 500,000**		**Pages: 1,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	4,631,313	5,207,868	17,368,607	18,851,389	25,184,583	24,334,993
2	6,540,615	7,815,485	24,997,688	27,526,128	38,741,504	38,796,629
3	7,336,145	8,290,071	27,953,470	30,077,304	44,394,458	45,790,514
4	7,664,185	8,644,074	31,175,664	31,450,807	50,808,890	55,203,232
5	7,511,716	8,537,803	29,453,931	33,540,875	53,398,222	65,311,352

Table 18: Bayes: Throughput – EC2 vs. Azure

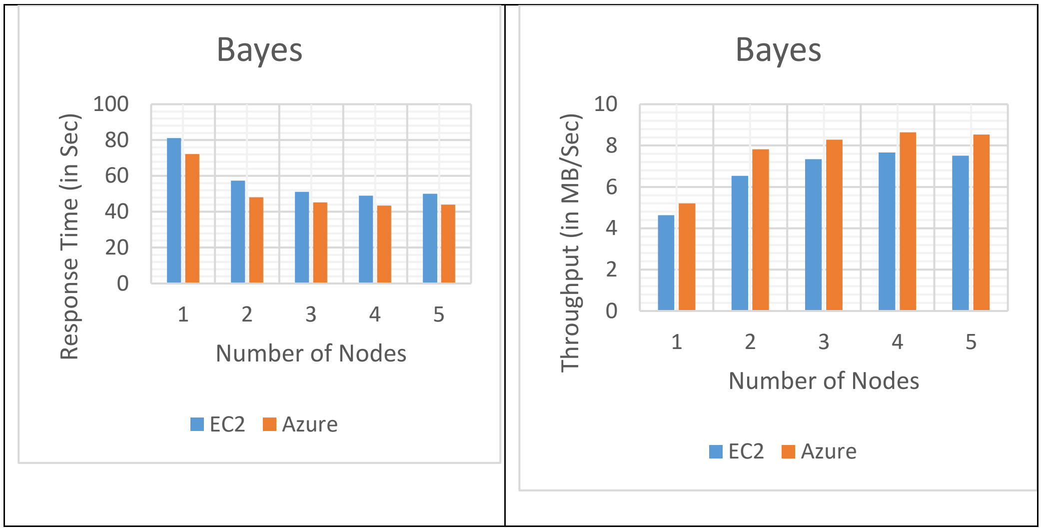


Figure 27: Bayes – EC2 vs. Azure (100,000 Pages)

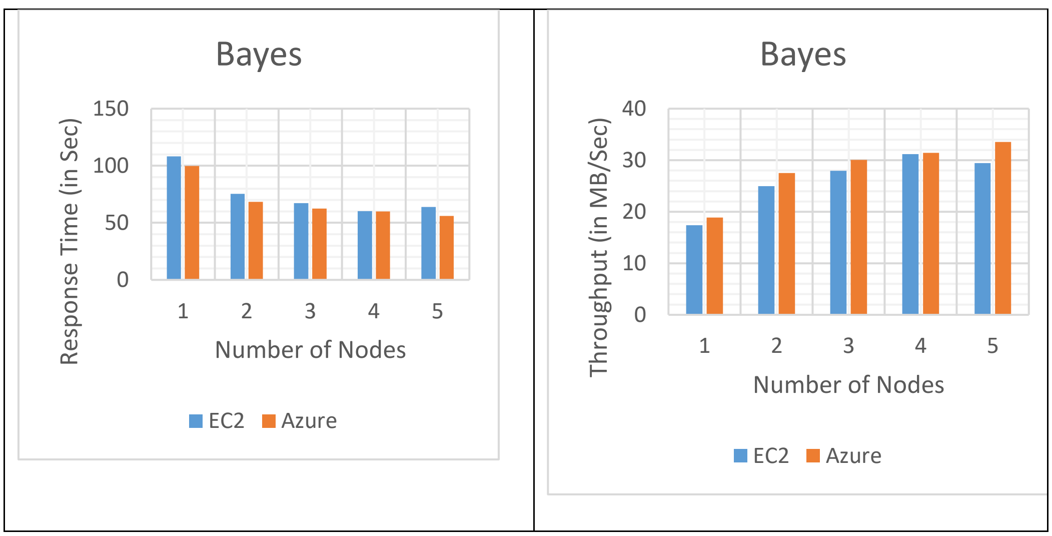


Figure 28: Bayes – EC2 vs. Azure (500,000 Pages)

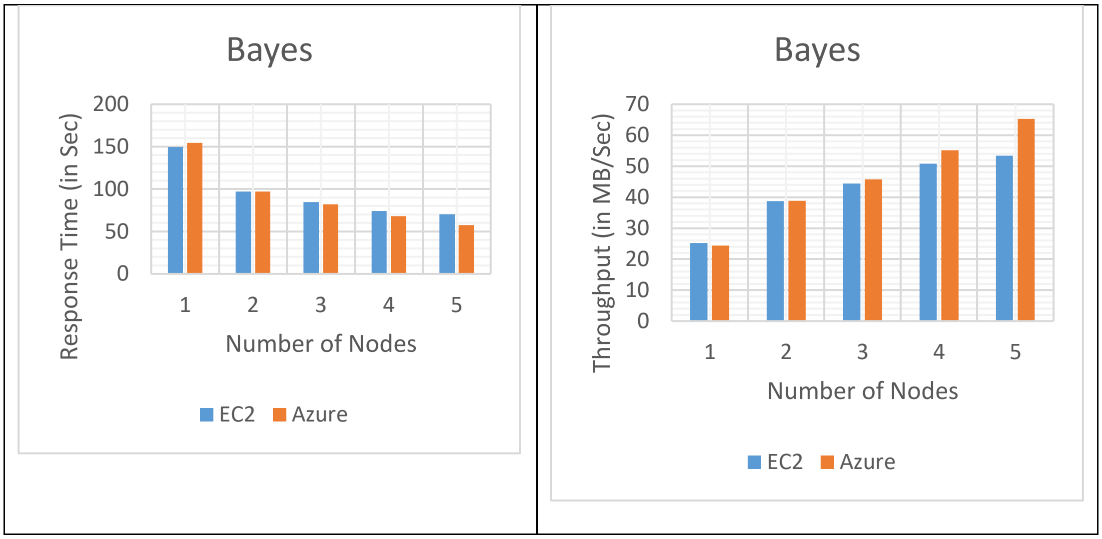


Figure 29: Bayes – EC2 vs. Azure (1,000,000 Pages)

Test results from Tables 17 and 18 indicate that Microsoft Azure performed better than Amazon EC2 cloud platform as Azure cloud shows better performance metrics than EC2 for the dataset (pages: 100,000) and (pages: 500,000). For the larger dataset of (pages: 1,000,000) both the Amazon EC2 and Azure clouds performed about the same.

Using the graphical results as shown in Figures 27, 28, and 29, it can be concluded that Microsoft Azure performed better than Amazon EC2 cloud platform as Azure cloud shows better performance values than EC2 for the dataset (pages: 100,000) and (pages: 500,000). With a larger dataset of (pages: 1,000,000) the difference in performance between Amazon EC2 and Microsoft Azure cloud does not show much noticeable change.

6.4.2 EC2 and Azure Performance for K-Means Clustering

Tables 19 and 20 show the tabulated performance values for response time and throughput, and Figures 30, 31, and 32 present the graphs plotted for response time and throughput for K-Means benchmark, with varied nodes and data sizes on Amazon EC2 and Microsoft Azure cloud platforms respectively.

K means – Response Time						
Data Size	**No. of Samples: 20,000,000 Samples\Input file: 4,000,000**		**No. of Samples: 80,000,000 Samples\Input file: 6,000,000**		**No. of Samples: 100,000,000 Samples\Input file: 8,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	221.719	218.452	572.877	477.846	2,269.021	1,153.92
2	122.049	123.575	544.284	376.277	606.333	552.377
3	101.169	93.396	328.871	353.736	542.956	382.072
4	82.811	69.448	314.64	206.232	373.57	262.047
5	87.722	65.934	252.769	307.307	354.825	291.266

Table 19: K-Means: Response Time – EC2 vs. Azure

K means – Throughput						
Data Size	**No. of Samples: 20,000,000 Samples\Input file: 4,000,000**		**No. of Samples: 80,000,000 Samples\Input file: 6,000,000**		**No. of Samples: 100,000,000 Samples\Input file: 8,000,000**	
#Nodes	**EC2**	**Azure**	**EC2**	**Azure**	**EC2**	**Azure**
1	18,114,693	18,385,602	31,548,945	37,823,176	10,620,523	20,883,756
2	32,907,862	32,501,490	33,206,267	48,032,842	39,744,144	43,626,362
3	39,699,628	43,003,680	54,956,666	51,093,622	44,383,336	63,072,402
4	48,500,461	57,832,791	57,442,326	87,637,484	64,507,854	91,961,362
5	45,785,227	60,915,031	71,502,651	58,813,023	67,915,730	82,736,052

Table 20: K-Means: Throughput – EC2 vs. Azure

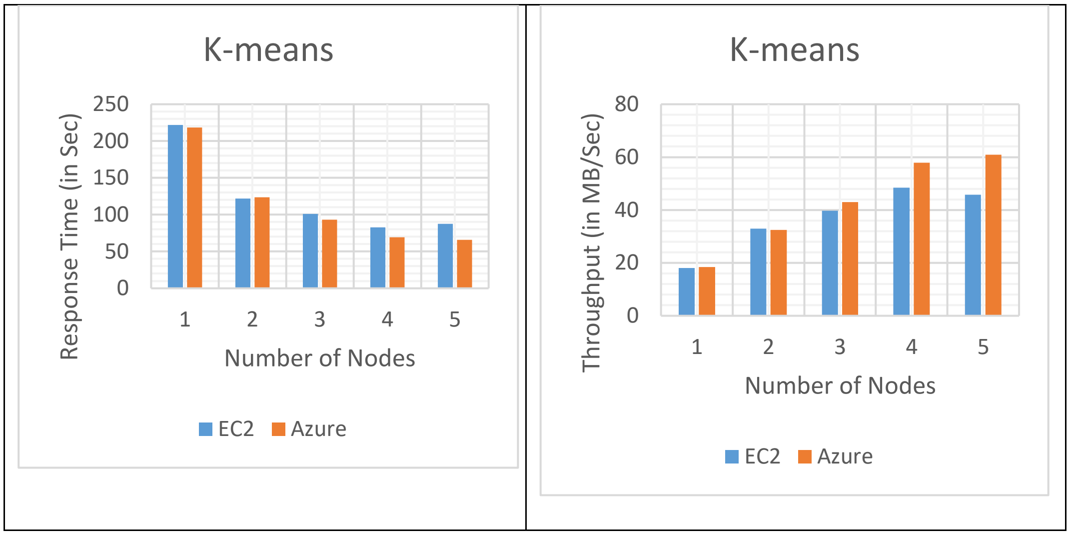


Figure 30: K-Means – EC2 vs. Azure (20,000,000 Samples)

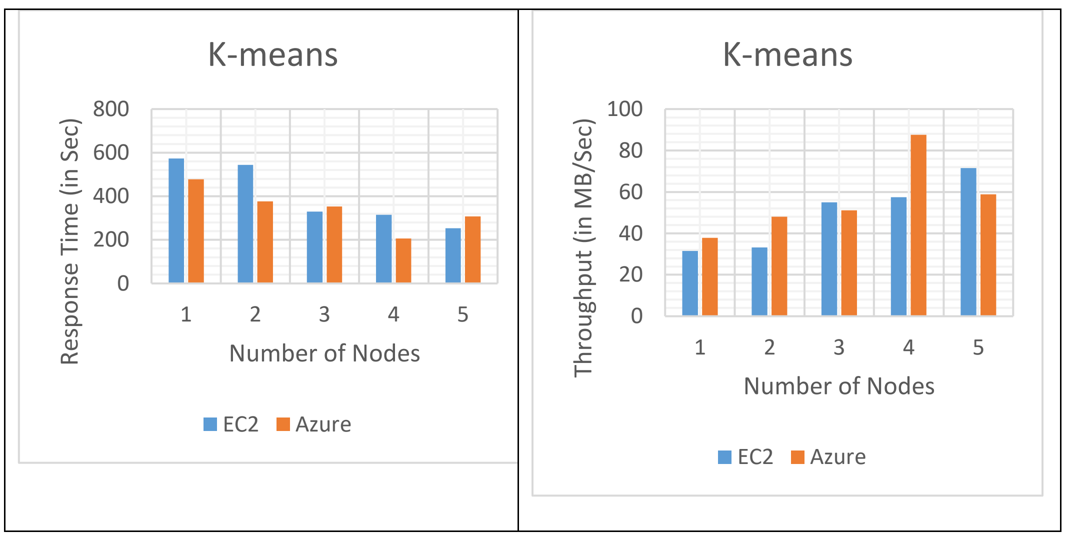


Figure 31: K-Means – EC2 vs. Azure (80,000,000 Samples)

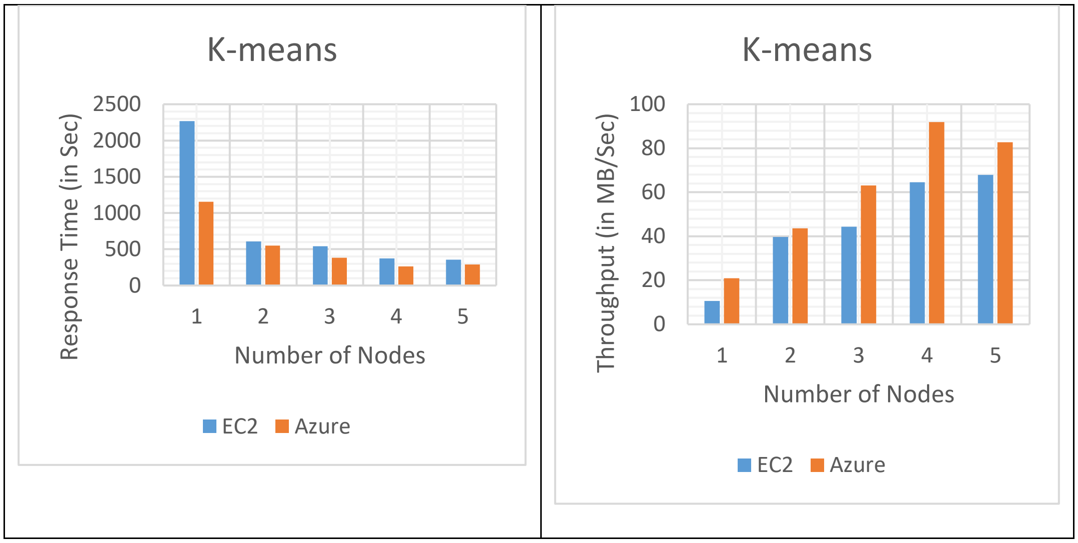


Figure 32: K-Means – EC2 vs. Azure (100,000,000 Samples)

Test results from Tables 19 and 20 indicate that Microsoft Azure performed better than Amazon EC2 cloud platform for dataset (samples: 20,000,000) in terms of response time, and for dataset (samples: 100,000,000) in terms of throughput. For larger dataset (samples: 20,000,000) in terms of throughput, (samples: 80,000,000) in terms of both response time and throughput, and (samples: 100,000,000) in terms of response time, performance of EC2 and Azure is almost equal.

Using the graphical results as shown in Figures 30, 31, and 32, it can be concluded that both Microsoft Azure and Amazon EC2 cloud platforms performed about the same for dataset (samples: 20,000,000) in terms of throughput, (samples: 80,000,000) in terms of both response time and throughput, and (samples: 100,000,000) in terms of response time. In two other cases, namely (samples: 20,000,000) in terms of response time, and (samples: 100,000,000) in terms of throughput both the EC2 and Azure performed about the same.

Chapter 7

CONCLUSIONS

7.1 Benchmark Results

This chapter is a discussion of the results obtained in Chapter 6. The two cloud platforms, Amazon EC2 and Microsoft Azure were tested using the HiBench benchmark suite, with the number of nodes increased by 1 from 1 to 5 for different sizes of dataset, such as 1GB, 100GB, and 1,000GB. Overall, testing with benchmarks WordCount, Sort, Join, Scan, PageRank, Bayes showed that Microsoft Azure was appropriate for smaller dataset of big data based applications computation i.e., up to 100 GB. Also, results of testing with TeraSort, Aggregation, and K-Means benchmarks revealed that both the Microsoft Azure and Amazon EC2 cloud platforms performed about the same. This was confirmed by results run on i2.2xlarge and G3 instances for dataset of 1GB and 100GB. Regarding computation of larger dataset of big data based applications i.e., benchmark workloads of 1,000 GB, both Microsoft Azure and Amazon EC2 cloud platforms showed similar performance results, thus neither cloud service is better. PageRank, the web search benchmark, showed that the Azure cloud showed better performance than EC2, with better response time and throughput values compared to EC2. This was also observed from the installation details. Microsoft Azure and Amazon EC2 installations of Hadoop were tuned on both the operating system and Hadoop configuration parameters, which yielded greater improvements in their performance. This also included increasing the open file handles limit in OS, vm.swappiness parameter set 0 to maximize the in-memory data, using improved compression codecs and fixes to optimize the map, shuffle, and reduce process on the input files. These parameters enhanced performance tuning of nodes in the running clusters on both Microsoft Azure and Amazon EC2. The performance tuning settings of Hadoop used for Microsoft Azure cluster and Amazon EC2 cluster enhanced the performance and scalability on big data computation applications which explain how each cloud platform is competitive with the other in terms of performance for larger dataset computations.

The performance of Amazon EC2 and Microsoft Azure cloud platforms was found to be almost the same for all WordCount, Sort, TeraSort, Aggregation, Join, Scan, Bayes, and K-Means Benchmarks, as these workloads are either I/O bound or CPU bound or both during big data computations. The only exception was the Page Rank benchmark values where Azure cloud showed better performance value than EC2.

Both Amazon EC2 and Microsoft Azure cloud platforms required a great deal of performance tuning and configuration settings for processing big data applications, but with all these changes made, both Microsoft Azure and Amazon EC2 showed that one cloud is equally competitive in performance to another cloud platform, and that both performed about the same with respect to big data application computations. The advantages of using Microsoft Azure include a stack of products that are simple to use, platform and services that can be easily integrated, flexibility in adding or removing auto-scaling, and load-balancing services for clients running test environments or batch processing. Advantages of using Amazon EC2 include support for elastic web-scale computing, complete control over instances, flexible cloud hosting services, the service can be combined with additional Amazon web services, and it is reliable, secure, inexpensive, and simple to start and deploy.

From a scaling and cost viewpoint, management of a large number of nodes and greater workloads, either of the cloud platform Microsoft Azure or Amazon EC2 are well suited to the tasks; however, the cost of Microsoft Azure is slightly higher than that of Amazon EC2. Either of the cloud service is acceptable as the performance is good in terms of both speed and throughput for the associated costs. With Microsoft Azure, it is easy to setup an internal network with subnets and other configurations for each node in the cluster and map the IPs and Domain names of our choice using the DNS server, and it is more generous with memory. Amazon EC2 enables the user to define virtual networks in a logically isolated area in AWS called Virtual Private Cloud (VPC), and can introduce any AWS resources inside the VPC. Security groups with added rules can be associated with instances. The security groups act as virtual firewalls and control the traffic of the associated instances. Either of the cloud platform, Microsoft Azure or Amazon EC2 are suitable options for large cluster sizes and larger dataset storage and computations.

7.2 Pricing Models

Table 21 offers basic information on pricing of Amazon EC2 and Microsoft Azure for i2.2xlarge and G3 instances types. Amazon EC2 has a base price of $1.705 per instance. Microsoft Azure has a base price of $2.20 per instance. As the number of nodes increase, the difference in price value becomes more significant as shown in Figure 33 below. The difference in price becomes especially significant when considering instance usage multiplied by number of hours times number of nodes times unit price of the instance.

Nodes	**Amazon EC2 (per hour) i2.2xlarge instance**	**Microsoft Azure (per hour) G3 instance**
1	$1.705	$2.20
2	$3.41	$4.40
3	$5.115	$6.60
4	$6.82	$8.80
5	$8.525	$11

Table 21: Pricing of Amazon EC2 vs Microsoft Azure

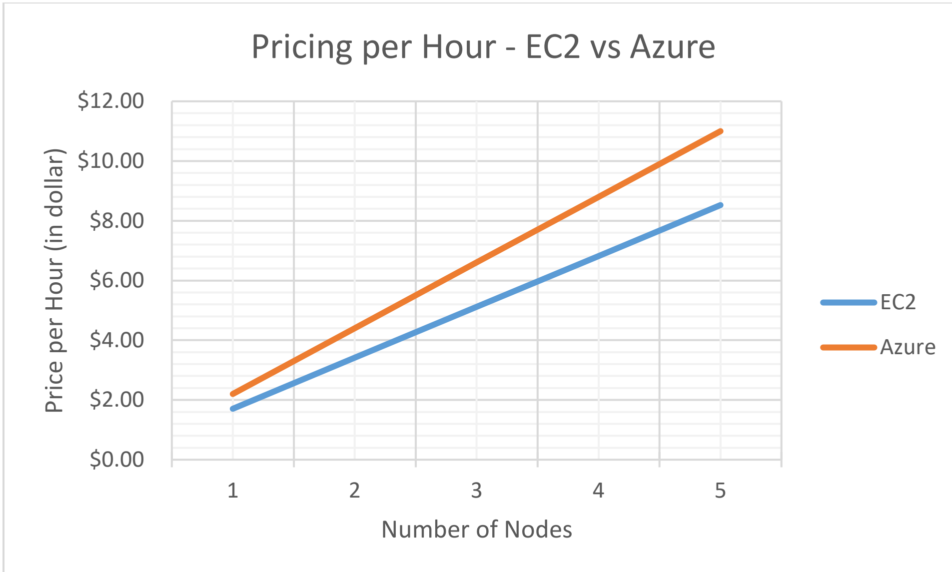


Figure 33: Pricing of Amazon EC2 vs Microsoft Azure

7.3 Future Research

This study focused on benchmarking two platforms, Amazon EC2 and Microsoft Azure public IaaS clouds, by changing the workloads for different dataset and count of nodes in the cluster to assess the performance of Hadoop based big data computation applications.

This research can be further extended by evaluating the performance in other cloud platforms like Google Compute Engine or Rackspace, and dataset size can be increased up to 10's or 100's of terabytes(TB) of data. This study helped illustrate the performance level of big data applications in Hadoop cluster on the two cloud services which will be helpful for further advanced study.

Also in this research, the instance i2.2xlarge provided by Amazon, and G3 provided by Microsoft Azure, had high storage capacity and were memory optimized instances.

Additional studies can be performed using other types of instances provided by Amazon and Azure, such as compute optimized instances (C3 instances) and Graphic optimized instances (G2 instances) from Amazon, and compute optimized (H-series instances), GPU (N-series instances), and High Performance Compute (H-series instances).

In this research experiment, benchmarking was performed with MapReduce which can be also be compared with Spark in Scala language, where Spark supports fast big-scale data processing and has an advanced DAG execution engine that takes care of cyclic data flow and in-memory computing.

Other research could evaluate cloud performance with the help of new benchmarks. This research employs HiBench big data benchmark suite which is a group of Hadoop benchmarks. Additional benchmarks can be developed to test the Hadoop performance on big data computation based applications.

REFERENCES

Print Publications:

[Bautista14]
Bautista Villalpando Luis Eduardo, April Alain, and Abran Alain, “Performance Analysis Model for Big Data Applications in Cloud Computing,” Journal of Cloud Computing: Advances, Systems and Applications pp. 3-19, 2014

[Han14]
Han Rui and Lu Xiaoyi, “On Big Data Benchmarking,” Department of Computing, Imperial College London, Ohio State University, 2014. Source: arXiv:1402.5194, 2014.

[Huang10]
Huang Shengsheng, Huang Jie, Dai Jinquan, Xie Tao, and Huang Bo, “The HiBench Benchmark Suite: Characterization of the MapReduce-Based Data Analysis,” Conference: Data Engineering Workshops (ICDEW), Intel China Software Center, Shanghai, China, pp. 41-51, 2010.

[Huang12]
Huang Shengsheng, Huang Jie, Liu Yan, Yi Lan, and Dai Jinquan, “HiBench: A Representative and Comprehensive Hadoop Benchmark Suite,” Intel Asia-Pacific Research and Development Ltd., Shanghai, P.R. China, 200241.

[Hwang14]
Hwang Kai, Bai Xiaoying, Shi Yue, Li Muyang, Chen Wen-Guang, and Wu Yongwei, “Cloud Performance Modeling with Benchmark Evaluation of Elastic Scaling Strategies,” IEEE Transactions on Parallel and Distributed Systems, TPDS-2014-07-0595 R1 (Final Version), Vol 27, pp. 130-143, 2014, ISSN: 1045-9219.

[Mell11]
Mell Peter and Grance Timothy, “The NIST Definition of Cloud Computing,” Recommendations of the National Institute of Standards and Technology, Special Publication 800-145, September 2011.

[YCSB10]
Cooper Brian, Silberstein Adam, Tam Erwin, Ramakrishnan Raghu, and Sears Russell, “Benchmarking Cloud Serving Systems with YCSB,” In proceedings of the 1st ACM symposium on cloud computing ACM, 143-154, 2010.

[Zheng15]
Zheng Zhigao, Wang Ping, Liu Jing, and Sun Shengli, "Real-Time Big Data Processing Framework: Challenges and Solutions," published in International Journal of Applied Mathematics and Information Sciences. 9, No. 6, 3169-3190 (2015).

Electronic Sources:

[Azure16]
"Microsoft Azure Cloud," https://azure.microsoft.com/en-gb/, last accessed July 25, 2016.

[AzureType16]
"Virtual Machine Series," https://azure.microsoft.com/en-us/pricing/details/virtual-machines/series/#g-series, last accessed July 25, 2016.

[AzureStorage17]
"Azure Storage Service Encryption," https://docs.microsoft.com/en-us/azure/storage/storage-service-encryption, last accessed July 16, 2017.

[Bayes17]
"Mahout Naïve Bayessian," http://cwiki.apache.org/MAHOUT/naivebayes.html, last accessed July 16, 2017.

[BenchCloud14]
"Bench Cloud," https://github.com/Georges1er/BenchCloud, last accessed July 16, 2017.

[BigData16]
"Big Data," http://www.sas.com/en_th/insights/big-data/what-is-big-data.html, last accessed July 25, 2016.

[Coles16]
"Advantages of Cloud Computing," https://www.skyhighnetworks.com/cloud-security-blog/11-advantages-of-cloud-computing-and-how-your-business-can-benefit-from-them/, last accessed June 14, 2017.

[EC216]
"Amazon Elastic Compute Cloud," https://aws.amazon.com/ec2/, last accessed July 25, 2016.

[EC2Type16]
"Amazon EC2 Instance Types," https://aws.amazon.com/ec2/instance-types/, last accessed July 25, 2016.

[GridMix13]
"GridMix," https://hadoop.apache.org/docs/r.1.2.1/gridmix.html, last accessed July 16, 2017.

[Hadoop16]
"Welcome to Apache Hadoop," http://hadoop.apache.org/, last accessed July 25, 2016.

[HiBench16]
"HiBench Big Data Benchmark Suite," https://github.com/intel-hadoop/HiBench/, last accessed July 25, 2016.

[Hive17]
"Hive Homepage," http://hadoop.apache.org/hive, last accessed July 16, 2017.

[Hornung16]
Hornung Thomas, Przyjaciel-Zablocki Martin, and Schatzle Alexander, "Gaint Data: MapReduce and Hadoop," in University of Freiburg computer science department, last accessed October 21, 2016.

[KMeans17]
"Mahout KMeans," http://cwiki.apache.org/MAHOUT/k-means.html, last accessed July 16, 2017.

[Mahout17]
"Mahout Homepage," https://lucene.apache.org/mahout, last accessed July 16, 2017.

[Noll11]
Noll, M.G., "Running Hadoop on Ubuntu Linux (Multi-Node Cluster)," http://www.michael-noll.com/tutorials/running-hadoop-on-ubuntu-linux-multi-node-cluster/, last revision July 7, 2011, last accessed July 25, 2016.

[PigMix13]
"PigMix," https://cwiki.apache.org/confluence/display/PIG/PigMix, last accessed July 16, 2017.

[TPC-W13]
"TPC Transaction Processing Performance Council," http://www.tpc.org/, last accessed July 16, 2017.

[YARN16]
"Apache Hadoop YARN," http://hadoop.apache.org/docs/current/hadoop-yarn/hadoop-yarn-site/YARN.html, last accessed July 25, 2016.

[ZipFian17]
"ZipFian Distribution," https://en.wikipedia.org/wiki/Zipf%27s_law, last accessed July 16, 2017.

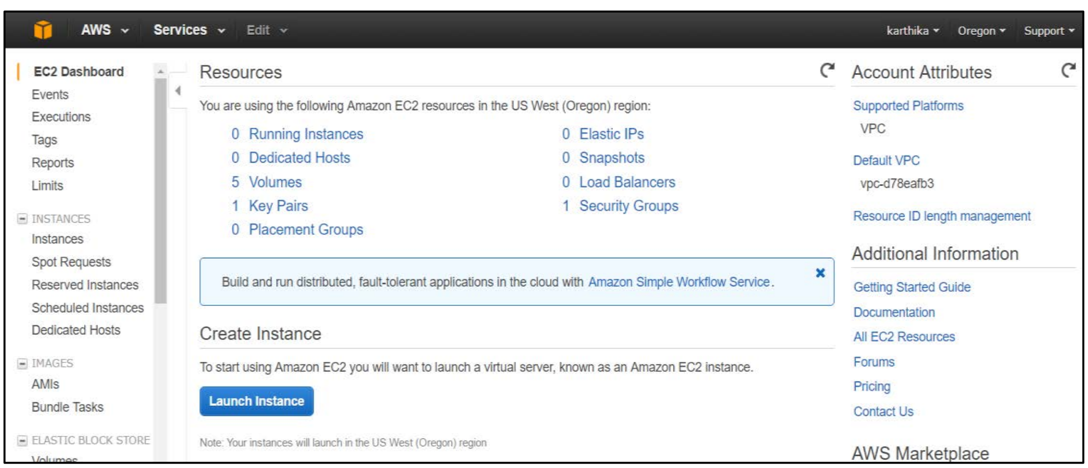
APPENDIX A

Create Instance on Amazon EC2

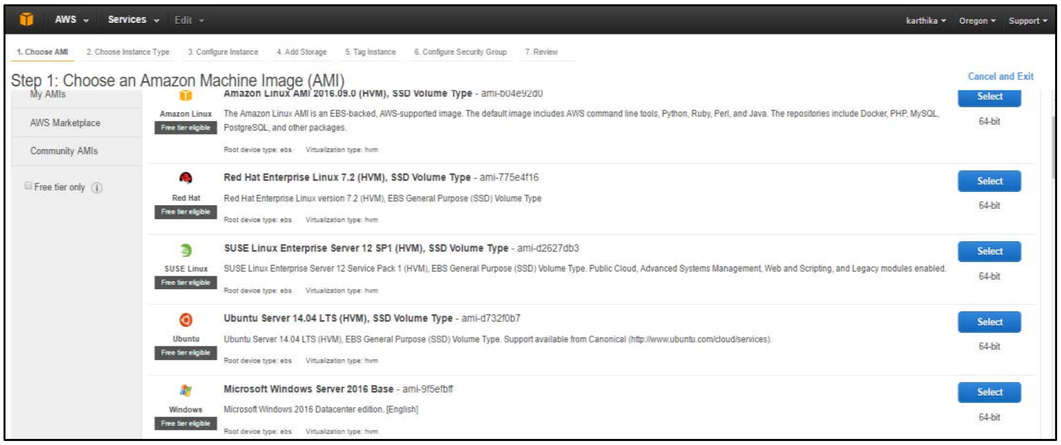
The steps to create instance on Amazon EC2 are explained as below:

1. Create an AWS account and Log in into the AWS EC2 console by providing the correct account credentials.

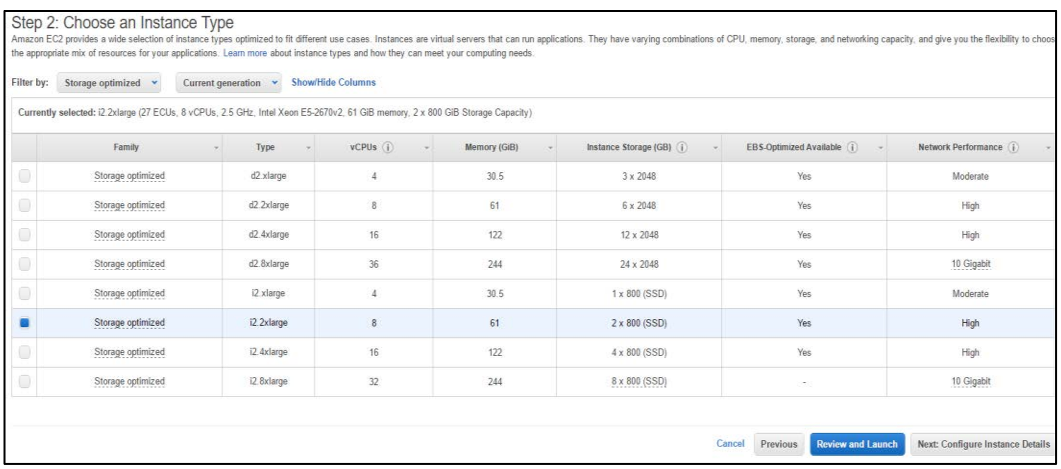
2. The EC2 dashboard page will be shown after logging in into the console and then click Launch Instance.



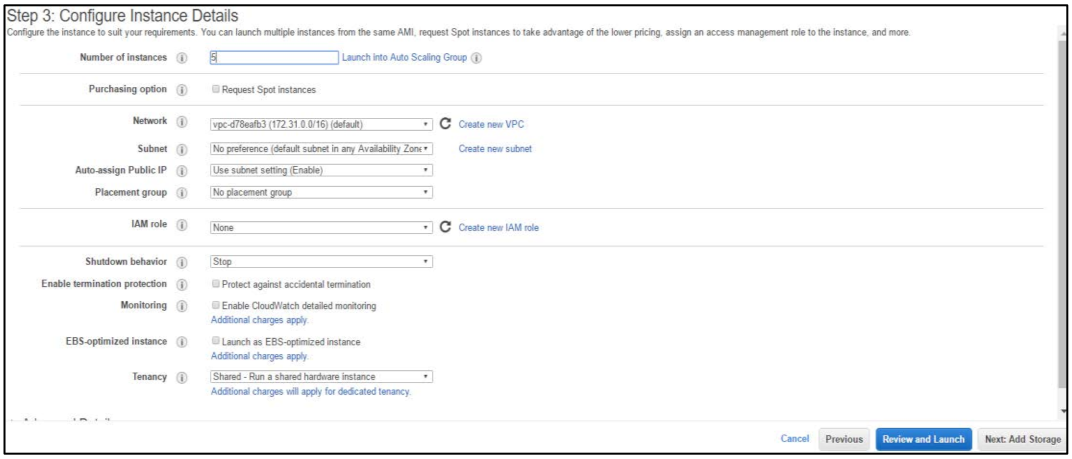
3. Choose the suitable Amazon Machine Image (AMI) template for the instance. Select Ubuntu server 14.04.



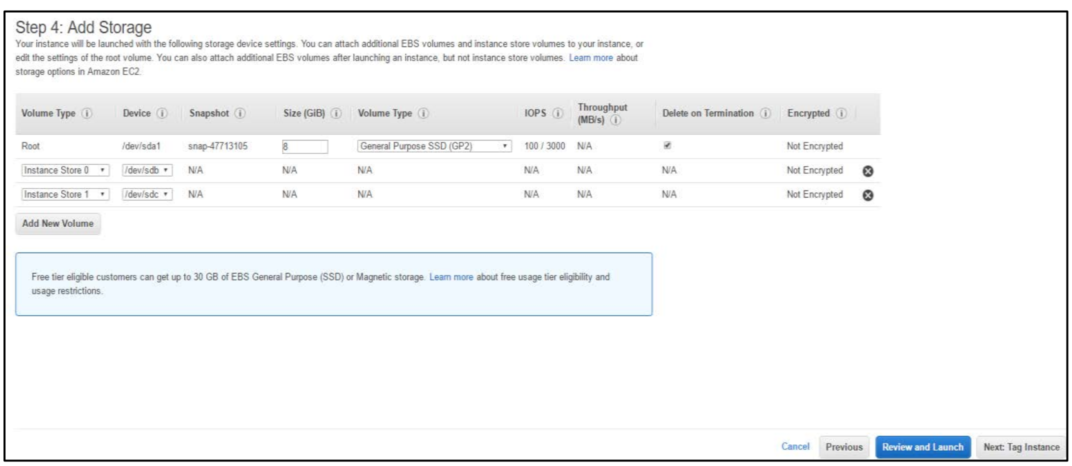
4. Choose the appropriate Instance type i.e. hardware to be created for the experiment.



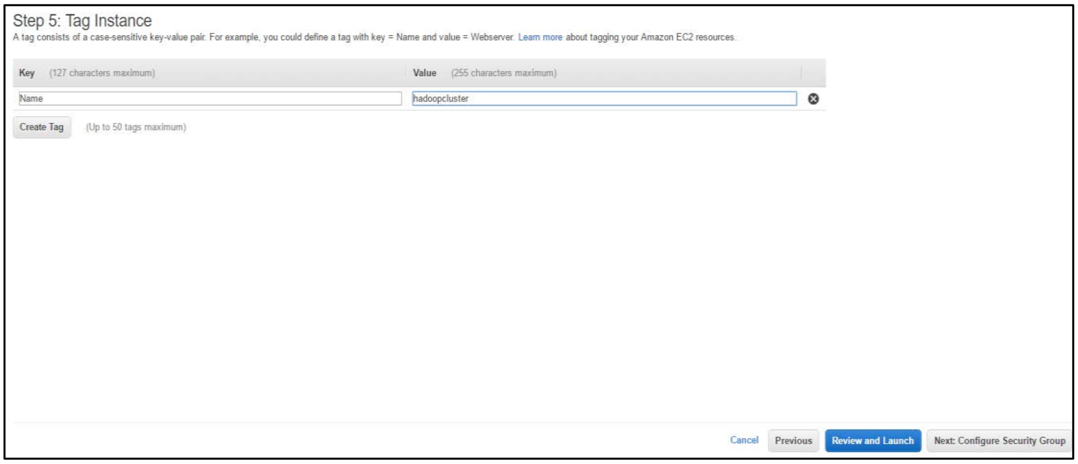
5. Configure the instance details by providing the number of instances to be created, network, subnet and other details as per requirement.



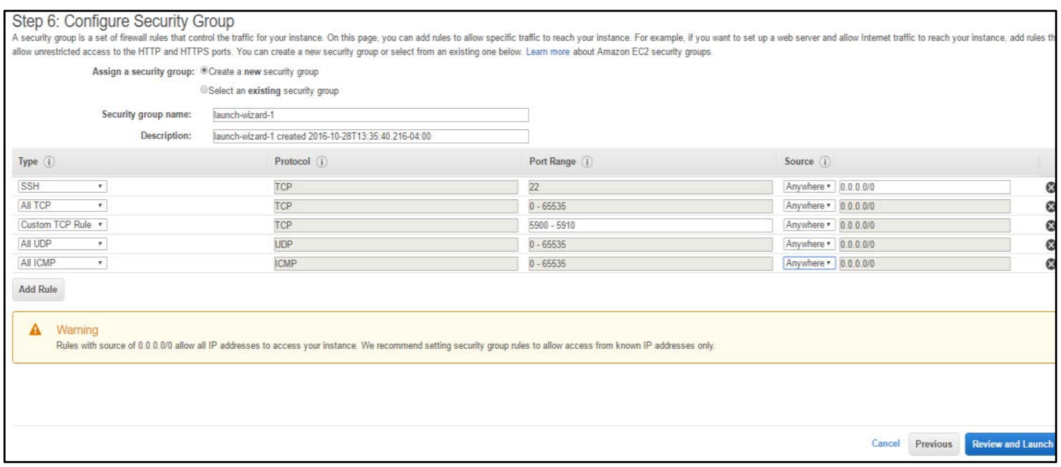
6. Add the storage volume by providing the required size and EBS volume type of instance that need to be launched.



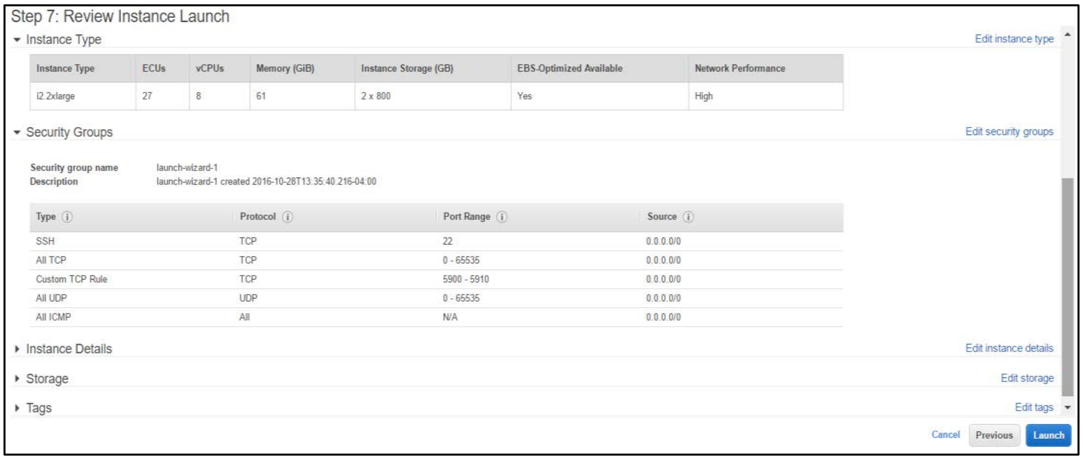
7. Create a case-sensitive key-value pair tag for the instance.



8. Configure security group for the instance by adding the set of firewall rules so as to control the traffic and unrestricted access to the http/https ports of the instances.



9. Finally review all the configured values and launch the instance and create the key pair and save the file to use while access the instances via SSH.



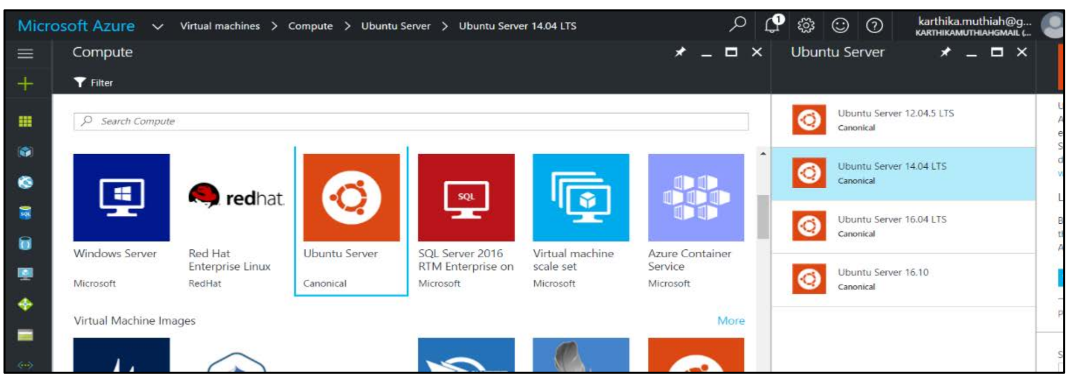
APPENDIX B

Create Instance on Microsoft Azure

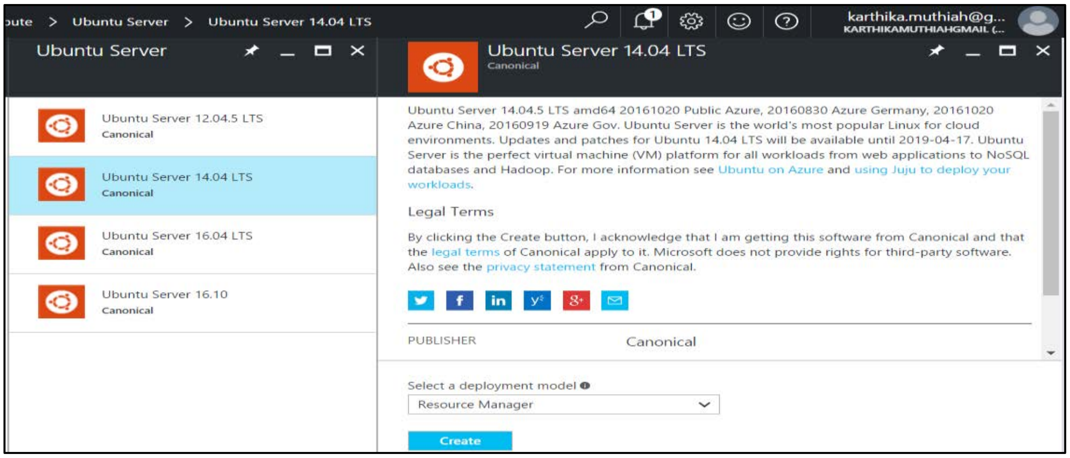
The steps to Create Instance on Microsoft Azure are explained as below,

1. Create a Microsoft Account and login into azure portal using the https://portal.azure.com URL.

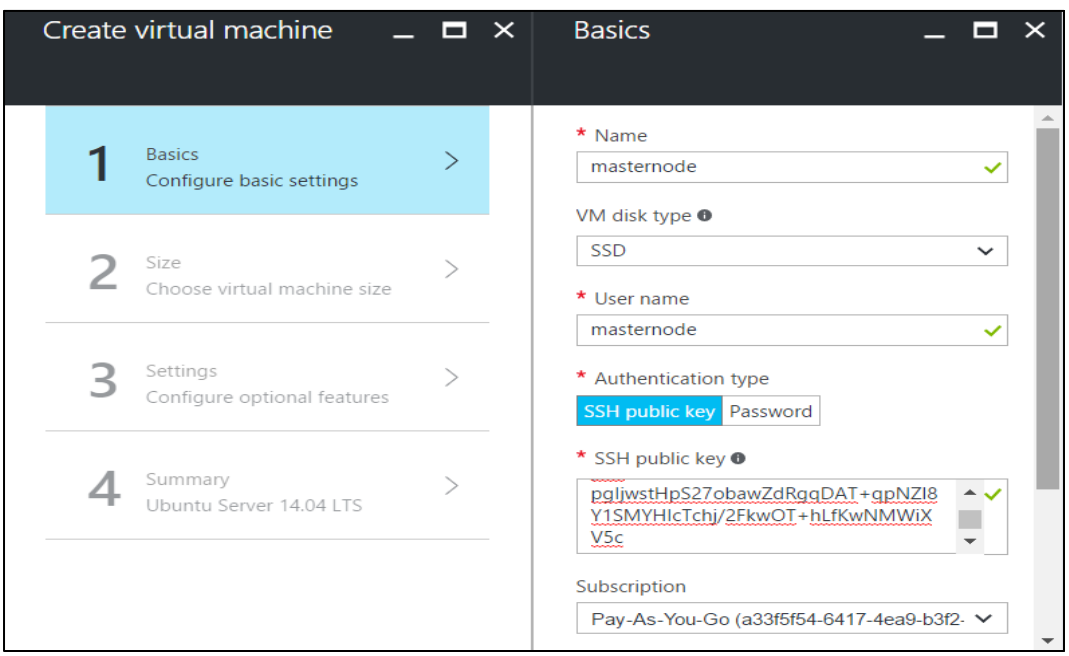
2. In the portal dashboard page, go to virtual machines and click add and search for the Ubuntu Server compute resource, and select the Ubuntu 14.04 template to create the virtual machine.

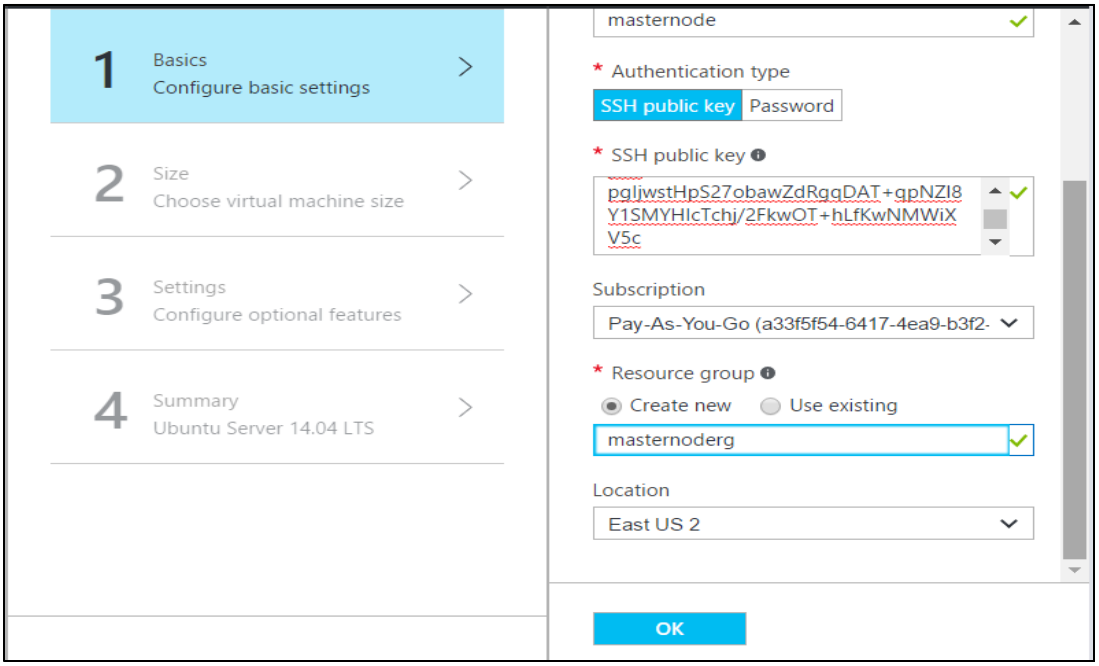


3. Select “Resource Manager” as the deployment model and click Create.

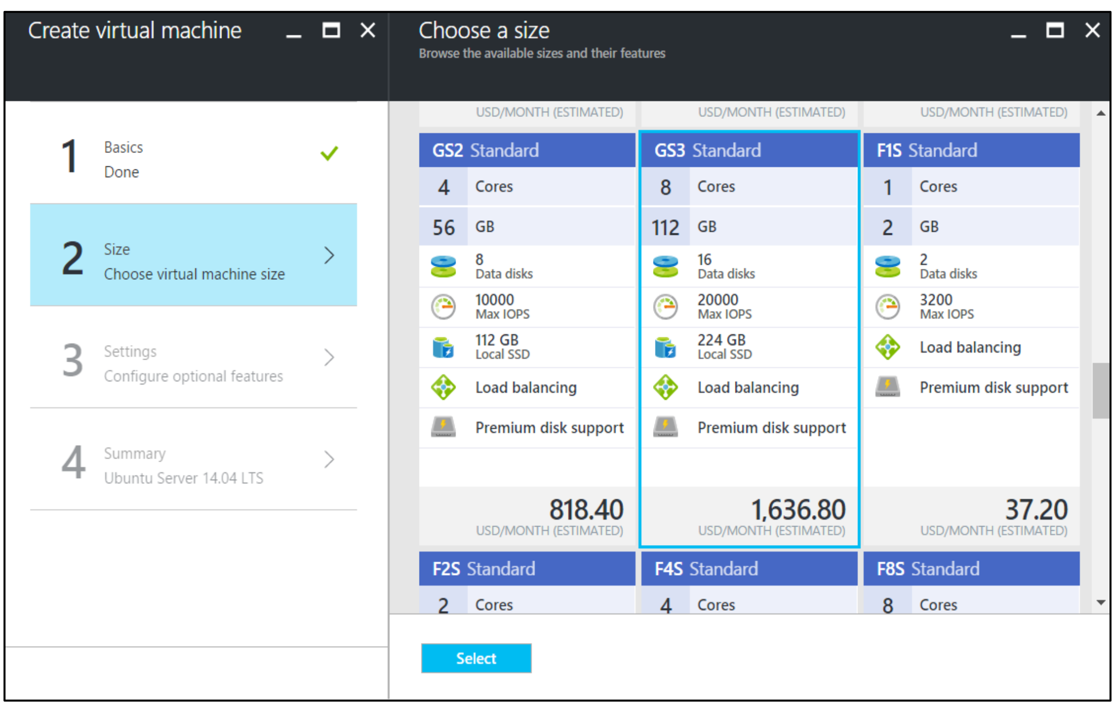


4. Configure the required basic settings by selecting the correct subscription ID and click OK.

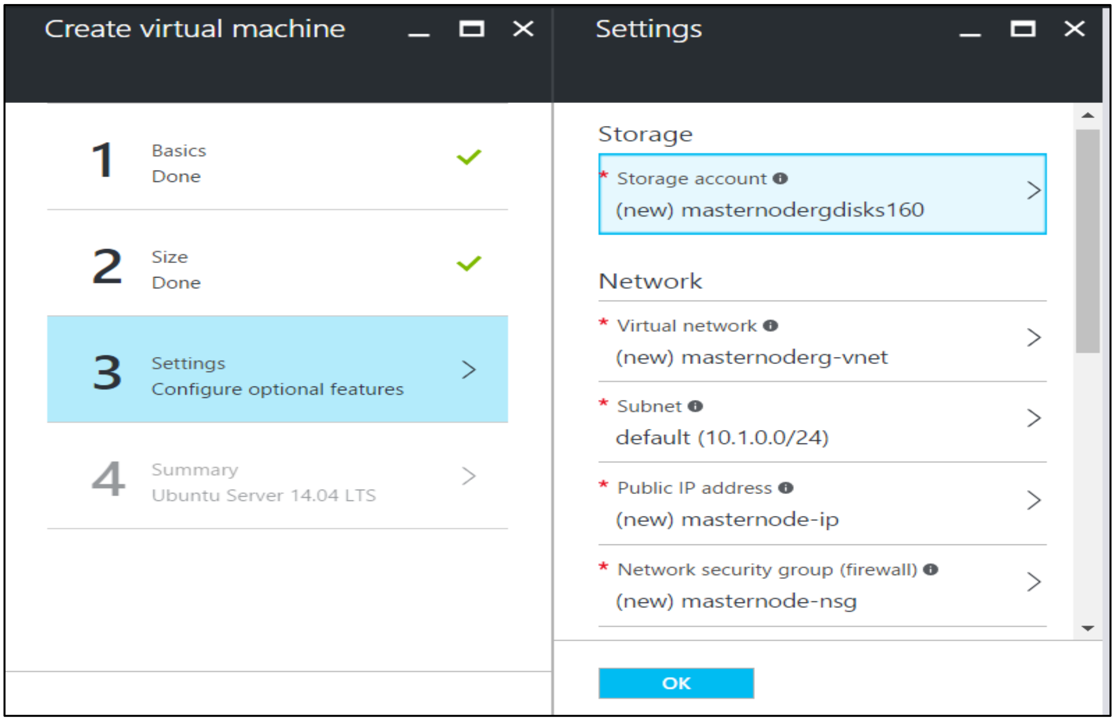




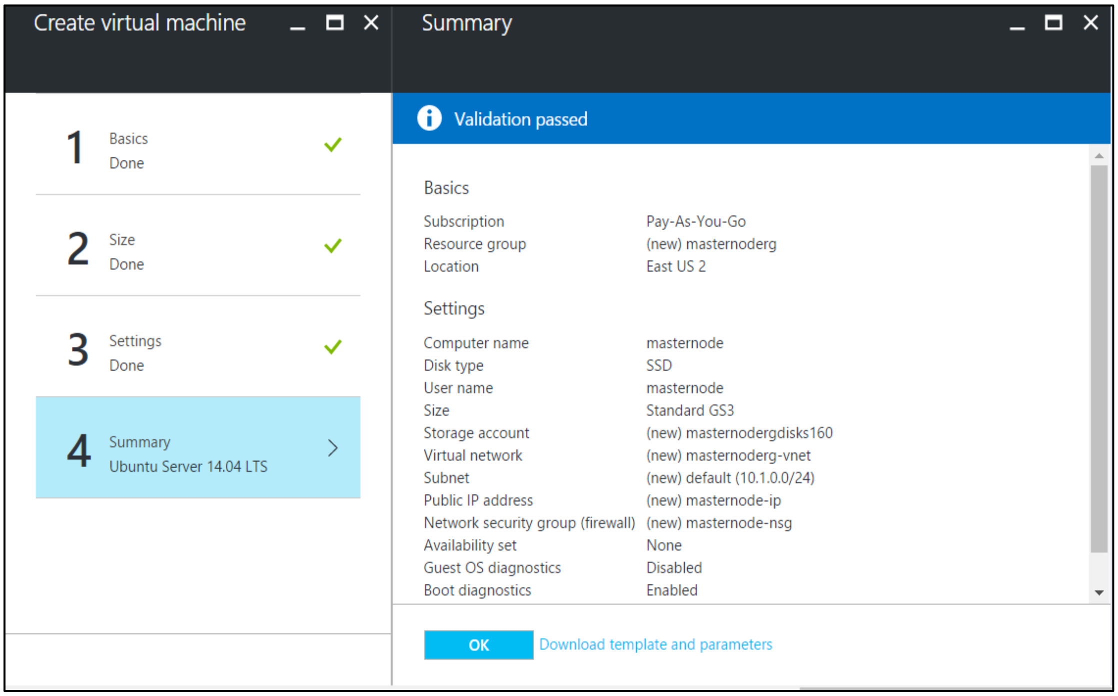
5. Choose the size as GS3 standard instance type and click Select.



6. Configure the storage settings with the default values and click OK.



7. Finally review the validation summary details and click OK to launch the virtual machine.



APPENDIX C

Hadoop Prerequisites

The Java JDK software is the prerequisite to be installed before Hadoop, which can then be downloaded from Oracle's website

To install Java JDK commands:

```
$sudo apt-get update
```

```
$sudo apt-get install openjdk-7-jdk
```

To create soft link for java JDK:

```
$sudo ln –s java-7-openjdk-amd64 jdk
```

To setup environment variables for java:

```
$sudo vi ~/.bashrc
```

Add the entries shown below to the end and save the file:

```
#java home environment variables

export JAVA_HOME=/usr/lib/jvm/jdk

export PATH=$PATH:$JAVA_HOME/bin
```

To check for Java version that is installed in the system:

```
$java –version
```

To check the Java class path that is set:

```
$echo $JAVA_HOME
```

To create specific group and user in that group:

```
$sudo addgroup hadoop
```

```
$sudo adduser --ingroup hadoop hduser
$sudo adduser hduser sudo
```

To configure hostnames and ipaddresses in /etc/hosts file to resolve hostnames and avoid unreachable host's error:

```
$sudo vi /etc/hosts
```

Add the following entries i.e. ipaddress and hostname and save the file:

```
172.31.11.205 masternode
172.31.11.206 node1
172.31.11.207 node2
172.31.11.208 node3
172.31.11.209 node4
```

Because it is not supported by Hadoop, the command to disable IPv6 is as below:

```
$sudo vi /etc/sysctl.conf
```

Add the following entries at the end and save the file:

```
# disable ipv6
net.ipv6.conf.all.disable_ipv6 = 1
net.ipv6.conf.default.disable_ipv6 = 1
net.ipv6.conf.lo.disable_ipv6 = 1
```

To confirm that IPv6 is disabled, execute the following command and check if it returns one:

```
$cat /proc/sys/net/ipv6/conf/all/disable_ipv6
```

Hadoop distributed cluster setup requires the master node to securely access and communicate with its slave nodes without requiring any password i.e. key based authentication. Hence, it is necessary to install SSH on port number 22 in all the Hadoop cluster nodes.

To generate the SSH key using the RSA algorithm without using a passphrase:

In the master node execute the following commands:

```
$su hduser
$ssh-keygen –t rsa –P “”
$cat /<home dir path>/.ssh/id_rsa.pub >> /<home dir
path>/.ssh/authorized_keys
$sudo chmod 600 /<home dir path>/.ssh/authorized_keys
$sudo chown –R hduser /<home dir path>/.ssh/authorized_keys
```

In order for the master node to connect to the slave nodes without password, it is necessary to copy the public key from the master and paste it in the authorized_keys file in all the slave nodes:

```
$su hduser
$sudo mkdir .ssh
$sudo vi .ssh/authorized_keys
```

To verify SSH to the nodes from master:

```
$ssh localhost
$ssh <slave-nodes>
```

APPENDIX D

Hadoop Installation and Configuration

Hadoop can be installed in all the nodes by downloading the package file from Hadoop archives.

```
$sudo wget
https://archive.apache.org/dist/hadoop/core/hadoop-
2.2.0/hadoop-2.2.0.tar.gz
$sudo tar -xvzf hadoop-2.2.0.tar.gz
$sudo mv hadoop-2.2.0 /usr/lib/hadoop
```

To configure the environment variables for Hadoop home:

```
$sudo vi ~/.bashrc
```

Add the following entries to the end and save the file:

```
#hadoop home environment variables
export HADOOP_HOME=/usr/lib/hadoop
export HADOOP_MAPRED_HOME=$HADOOP_HOME
export HADOOP_HDFS_HOME=$HADOOP_HOME
export YARN_HOME=$HADOOP_HOME
export PATH=$PATH:$HADOOP_HOME/bin
export PATH=$PATH:$HADOOP_HOME/sbin
```

Hadoop uses XML files to configure all its components. The configuration files for Hadoop2.2 installation will be located under $HADOOP_HOME/etc/hadoop directory.

Hadoop daemons process environment site-specific customization configurations are done in hadoop-env.sh script file which is mostly used by administrators.

The most commonly used properties are added into the *core-site.xml* file, HDFS related properties are added into the *hdfs-site.xml* file, Map Reduce related properties are added into the *mapred-site.xml* file and YARN related properties added into the *yarn-site.xml* file.Hadoop environment setting done in hadoop-env.sh

```
# Set Hadoop-specific environment variables here.
# The only required environment variable is JAVA_HOME.  All others are
# optional.  When running a distributed configuration it is best to
# set JAVA_HOME in this file, so that it is correctly defined on
# remote nodes.
# The java implementation to use.
export JAVA_HOME=/usr/lib/jvm/jdk
# The jsvc implementation to use. Jsvc is required to run secure datanodes.
#export JSVC_HOME=${JSVC_HOME}
export HADOOP_CONF_DIR=/usr/lib/hadoop/etc/hadoop
# Extra Java CLASSPATH elements.  Automatically insert capacity-scheduler.
for f in $HADOOP_HOME/contrib/capacity-scheduler/*.jar; do
  if [ "$HADOOP_CLASSPATH" ]; then
    export HADOOP_CLASSPATH=$HADOOP_CLASSPATH:$f
  else
    export HADOOP_CLASSPATH=$f
  fi
done
# The maximum amount of heap to use, in MB. Default is 1000.
#export HADOOP_HEAPSIZE="4096"
#export HADOOP_NAMENODE_INIT_HEAPSIZE=""
# Extra Java runtime options.  Empty by default.
export HADOOP_OPTS="$HADOOP_OPTS -XX:-PrintWarnings -Djava.net.preferIPv4Stack=true"

# Command specific options appended to HADOOP_OPTS when specified
export HADOOP_NAMENODE_OPTS="-Dhadoop.security.logger=${HADOOP_SECURITY_LOGGER:-INFO,RFAS}
-Dhdfs.audit.logger=${HDFS_AUDIT_LOGGER:-INFO,NullAppender}  $HADOOP_NAMENODE_OPTS"
export HADOOP_DATANODE_OPTS="-Dhadoop.security.logger=ERROR,RFAS $HADOOP_DATANODE_OPTS"

export HADOOP_SECONDARYNAMENODE_OPTS="-Dhadoop.security.logger=${HADOOP_SECURITY_LOGGER:-INFO,RFAS}
-Dhdfs.audit.logger=${HDFS_AUDIT_LOGGER:-INFO,NullAppender} $HADOOP_SECONDARYNAMENODE_OPTS"

# The following applies to multiple commands (fs, dfs, fsck, distcp etc)
export HADOOP_CLIENT_OPTS="-Xmx512m $HADOOP_CLIENT_OPTS"
#HADOOP_JAVA_PLATFORM_OPTS="-XX:-UsePerfData $HADOOP_JAVA_PLATFORM_OPTS"
```

1. Common configurations done in core-site.xml

```xml
<?xml version="1.0" encoding="UTF-8"?>
<?xml-stylesheet type="text/xsl" href="configuration.xsl"?>
<!--
  Licensed under the Apache License, Version 2.0 (the "License");
  you may not use this file except in compliance with the License.
  You may obtain a copy of the License at

    http://www.apache.org/licenses/LICENSE-2.0

  Unless required by applicable law or agreed to in writing, software
  distributed under the License is distributed on an "AS IS" BASIS,
  WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
  See the License for the specific language governing permissions and
  limitations under the License. See accompanying LICENSE file.
-->

<!-- Put site-specific property overrides in this file. -->

<configuration>
<property><name>fs.defaultFS</name><value>hdfs://masternode:9000</value></property>
<property><name>dfs.permissions.enabled</name><value>true</value></property>
</configuration>
```

2. HDFS related configurations done in hdfs-site.xml

```
<?xml version="1.0" encoding="UTF-8"?>
<?xml-stylesheet type="text/xsl" href="configuration.xsl"?>
<!--
  Licensed under the Apache License, Version 2.0 (the "License");
  you may not use this file except in compliance with the License.
  You may obtain a copy of the License at

    http://www.apache.org/licenses/LICENSE-2.0

  Unless required by applicable law or agreed to in writing, software
  distributed under the License is distributed on an "AS IS" BASIS,
  WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
  See the License for the specific language governing permissions and
  limitations under the License. See accompanying LICENSE file.
-->

<!-- Put site-specific property overrides in this file. -->

<configuration>
<property><name>dfs.replication</name><value>1</value></property>
<property>
<name>dfs.blocksize</name>
<value>134217728</value>
<!--<value>268435456</value>-->
<!--<value>536870912</value>-->
</property>
<property><name>dfs.namenode.name.dir</name><value>/home/hduser/hadoop/hdfs/namenode</value><final>true</final></property>
<property><name>dfs.datanode.data.dir</name><value>/home/hduser/hadoop/hdfs/datanode</value><final>true</final></property>
</configuration>
```

3. Map reduce related configurations done in mapred-site.xml

```
<?xml version="1.0"?>
<?xml-stylesheet type="text/xsl" href="configuration.xsl"?>
<!--
  Licensed under the Apache License, Version 2.0 (the "License");

    http://www.apache.org/licenses/LICENSE-2.0

  Unless required by applicable law or agreed to in writing, software
  distributed under the License is distributed on an "AS IS" BASIS,
  See the License for the specific language governing permissions and
  limitations under the License. See accompanying LICENSE file.
-->

<!-- Put site-specific property overrides in this file. -->

<configuration>
<property><name>mapreduce.framework.name</name><value>yarn</value></property>
<property><name>mapreduce.reduce.shuffle.parallelcopies</name><value>20</value></property>
<property><name>mapreduce.reduce.shuffle.input.buffer.percent </name><value>0.6</value></property>
<property><name>mapreduce.cluster.local.dir</name><value>/home/hduser/hadoop/mapred/local</value></property>
<property><name>mapreduce.map.speculative</name><value>true</value></property>
<property><name>mapreduce.reduce.speculative</name><value>true</value></property>
<property><name>mapreduce.task.io.sort.factor</name><value>100</value></property>
<property><name>mapreduce.task.io.sort.mb</name><value></value>1000</property>
<property><name>mapreduce.map.sort.spill.percent</name><value>0.98</value></property>
<property><name>mapreduce.map.memory.mb</name><value>1624</value></property>
<property><name>mapreduce.map.cpu.vcores</name><value>6</value></property>
<property><name>mapreduce.reduce.memory.mb</name><value>1624</value></property>
<property><name>mapreduce.reduce.cpu.vcores</name><value>4</value></property>
</configuration>
```

4. YARN related configurations done in yarn-site.xml

```xml
<?xml version="1.0"?>
<!--
  Licensed under the Apache License, Version 2.0 (the "License");
  you may not use this file except in compliance with the License.
  You may obtain a copy of the License at

    http://www.apache.org/licenses/LICENSE-2.0

  Unless required by applicable law or agreed to in writing, software
  distributed under the License is distributed on an "AS IS" BASIS,
  WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
  See the License for the specific language governing permissions and
  limitations under the License. See accompanying LICENSE file.
-->
<configuration>
<!-- Site specific YARN configuration properties -->
<property><name>yarn.resourcemanager.hostname</name><value>masternode</value></property>
<property><name>yarn.nodemanager.aux-services</name><value>mapreduce_shuffle</value></property>
</configuration>
```

Once the configuration changes listed added to the first node of the cluster (generally the master node), similar configurations can be either added or copied to all its slave nodes by executing the following commands.

```
$for i in `cat /usr/lib/hadoop/etc/hadoop/slaves`; do \
>echo $i; rsync -avxP --exclude=logs /usr/lib/hadoop/
$i:/usr/lib/hadoop/; \
>done
```

APPENDIX E

Starting an Hadoop Multi-Node Cluster

Hadoop uses hadoop.tmp.dir as the base temporary directory for both the local file system and HDFS as the default settings. As a result of creating HDFS namenode and datanode directory under the Hadoop folder, HDFS stores its transaction files and blocks in the respective folders created in the local filesystem, and also sets appropriate permissions.

```
$sudo mkdir /$HADOOP_HOME/hdfs/namenode
$sudo mkdir /$HADOOP_HOME/hdfs/datanode
$sudo chmod 750 /$HADOOP_HOME/hdfs/namenode
$sudo chmod 750 /$HADOOP_HOME/hdfs/datanode
```

The Hadoop Named Node should be formatted when the Hadoop is installed for the very first time.

```
$hdfs namenode -format
```

Start the HDFS layer after properly formatting the named node.

```
$/$HADOOP_HOME/sbin/start-dfs.sh
```

Start the Map Reduce layer after the successful start of the HDFS layer.

```
$/$HADOOP_HOME/sbin/start-yarn.sh
```

The configuration includes the first node as the master node and the remaining nodes in the multi-node cluster as slave nodes. The configuration file named ‘slaves’ in the Hadoop configuration directory of the master node contains information about all its slave nodes. After making the necessary changes in the 'slaves' configuration file on the master node, and configuring the SSH connection between master node and slave nodes, we can execute the commands mentioned below on the master node in order to start the Hadoop multi node cluster [Noll11].

The multi-node Hadoop cluster is started by performing the following steps. First, the HDFS layer is started. Following the successful start of the HDFS layer, the Map Reduce layer is started from the master node, which then automatically starts the slave node(s) HDFS layer and Map Reduce layer as configured in the 'slaves' configuration file

```
$ /$HADOOP_HOME/sbin/start-dfs.sh
$ /$HADOOP_HOME/sbin/start-yarn.sh
```

To stop the Hadoop cluster the Map Reduce layer is stopped first, which is followed by stopping the HDFS layer by executing the commands listed below from the master node, which then automatically stops the Hadoop daemons running in the slave nodes.

```
$ /$HADOOP_HOME/sbin/stop-yarn.sh
$ /$HADOOP_HOME/sbin/stop-dfs.sh
```

1. Starting Hadoop DFS Script from Master Node :

```
hduser@ip-172-31-11-205:/usr/lib/hadoop$ ./sbin/start-dfs.sh
16/10/29 22:07:26 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... using builtin-java classes where applicable
Starting namenodes on [masternode]
masternode: starting namenode, logging to /usr/lib/hadoop/logs/hadoop-hduser-namenode-ip-172-31-11-205.out
masternode: starting datanode, logging to /usr/lib/hadoop/logs/hadoop-hduser-datanode-ip-172-31-11-205.out
node2: starting datanode, logging to /usr/lib/hadoop/logs/hadoop-hduser-datanode-ip-172-31-11-207.out
node4: starting datanode, logging to /usr/lib/hadoop/logs/hadoop-hduser-datanode-ip-172-31-11-209.out
node3: starting datanode, logging to /usr/lib/hadoop/logs/hadoop-hduser-datanode-ip-172-31-11-208.out
node1: starting datanode, logging to /usr/lib/hadoop/logs/hadoop-hduser-datanode-ip-172-31-11-206.out
Starting secondary namenodes [0.0.0.0]
0.0.0.0: starting secondarynamenode, logging to /usr/lib/hadoop/logs/hadoop-hduser-secondarynamenode-ip-172-31-11-205.out
16/10/29 22:07:42 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... using builtin-java classes where applicable
hduser@ip-172-31-11-205:/usr/lib/hadoop$ jps
15643 DataNode
15466 NameNode
15985 Jps
15864 SecondaryNameNode
```

2. Starting Hadoop Yarn Script from Master Node:

```
hduser@ip-172-31-11-205:/usr/lib/hadoop$ ./sbin/start-yarn.sh
starting yarn daemons
starting resourcemanager, logging to /usr/lib/hadoop/logs/yarn-hduser-resourcemanager-ip-172-31-11-205.out
OpenJDK 64-Bit Server VM warning: You have loaded library /usr/lib/jvm/java-7-openjdk-amd64/jre/lib/amd64/libhadoop.so which might have disabled stack guard.
 The VM will try to fix the stack guard now.
It's highly recommended that you fix the library with 'execstack -c <libfile>', or link it with '-z noexecstack'.
node3: starting nodemanager, logging to /usr/lib/hadoop/logs/yarn-hduser-nodemanager-ip-172-31-11-208.out
masternode: starting nodemanager, logging to /usr/lib/hadoop/logs/yarn-hduser-nodemanager-ip-172-31-11-205.out
node1: starting nodemanager, logging to /usr/lib/hadoop/logs/yarn-hduser-nodemanager-ip-172-31-11-206.out
node2: starting nodemanager, logging to /usr/lib/hadoop/logs/yarn-hduser-nodemanager-ip-172-31-11-207.out
node4: starting nodemanager, logging to /usr/lib/hadoop/logs/yarn-hduser-nodemanager-ip-172-31-11-209.out
node3: OpenJDK 64-Bit Server VM warning: You have loaded library /usr/lib/hadoop/lib/native/libhadoop.so.1.0.0 which might have disabled stack guard. The VM
will try to fix the stack guard now.
node3: It's highly recommended that you fix the library with 'execstack -c <libfile>', or link it with '-z noexecstack'.
masternode: OpenJDK 64-Bit Server VM warning: You have loaded library /usr/lib/jvm/java-7-openjdk-amd64/jre/lib/amd64/libhadoop.so which might have disabled
stack guard. The VM will try to fix the stack guard now.
masternode: It's highly recommended that you fix the library with 'execstack -c <libfile>', or link it with '-z noexecstack'.
node1: OpenJDK 64-Bit Server VM warning: You have loaded library /usr/lib/hadoop/lib/native/libhadoop.so.1.0.0 which might have disabled stack guard. The VM
will try to fix the stack guard now.
node1: It's highly recommended that you fix the library with 'execstack -c <libfile>', or link it with '-z noexecstack'.
node2: OpenJDK 64-Bit Server VM warning: You have loaded library /usr/lib/hadoop/lib/native/libhadoop.so.1.0.0 which might have disabled stack guard. The VM
will try to fix the stack guard now.
node2: It's highly recommended that you fix the library with 'execstack -c <libfile>', or link it with '-z noexecstack'.
node4: OpenJDK 64-Bit Server VM warning: You have loaded library /usr/lib/hadoop/lib/native/libhadoop.so.1.0.0 which might have disabled stack guard. The VM
will try to fix the stack guard now.
node4: It's highly recommended that you fix the library with 'execstack -c <libfile>', or link it with '-z noexecstack'.
hduser@ip-172-31-11-205:/usr/lib/hadoop$ jps
15643 DataNode
15466 NameNode
16045 ResourceManager
16210 NodeManager
16509 Jps
15864 SecondaryNameNode
hduser@ip-172-31-11-205:/usr/lib/hadoop$
```

APPENDIX F

HiBench Prerequisites

Prerequisites for installing HiBench benchmark are provided below.

Setup JDK, Python, Hadoop YARN, Maven, and Spark runtime environments correctly before installing HiBench in the master node. HiBench 4.0 Benchmark was used in this study which supports Python version 2.6 or later.

Maven is a software tool associated with project management that can manage the builds, reporting, and documentation of its related projects by using the Project Object Model (POM) concept. The Maven package must be downloaded from maven binaries and installed as follows:

```
$sudo wget http://www-eu.apache.org/dist/maven/maven-
3/3.3.9/binaries/apache-maven-3.3.9-bin.tar.gz
$sudo tar –xvzf apache-maven-3.3.9-bin.tar.gz
```

To set the Spark runtime environment i.e. Spark, which is faster and also a common engine for big scale data processing, requires that the Scala shell be installed for Spark to execute interactively. Scala shell and Spark can be downloaded and installed using the commands listed below:

```
$sudo wget http://www.scala-lang.org/files/archive/scala-
2.10.4.tgz
$sudo wget http://d3kbcqa49mib13.cloudfront.net/spark-
1.3.0-bin-hadoop2.4.tgz
```

APPENDIX G

HiBench Benchmark Installation, Configuration and Execution

The HiBench 4.0 package can be downloaded the github website and unzipped. The extracted files are then moved to the hibench folder and folder permissions must be changed:

```
$sudo wget https://github.com/intel-
hadoop/HiBench/archive/HiBench-4.0.zip
$sudo unzip HiBench-4.0.zip
$sudo mv HiBench-4.0 hibench
$sudo chmod 755 hibench
```

The next step is to edit the bashrc file and add the environment variables for Maven, Scala, and Spark installations to the end, and save the file.

HiBench configurations can be copied and created from the template "conf/99-user_defined_properties.conf.template" file. The properties are set in the newly created conf/99-user_defined_properties.conf file. The following properties are required to be set:

```
hibench.hadoop.home      /usr/lib/hadoop
hibench.spark.home       /usr/lib/spark
hibench.hdfs.master      hdfs://masternode:9000
```

```
hibench.hadoop.version   hadoop2
hibench.spark.version    spark1.3
```

HiBench benchmarks can be executed by running all the workloads with all language APIs and only the required workloads and languages by commenting the lines in conf/benchmarks.lst and conf/languages.lst configuration files. The workloads can then be executed by running the following scripts:

For all workloads,

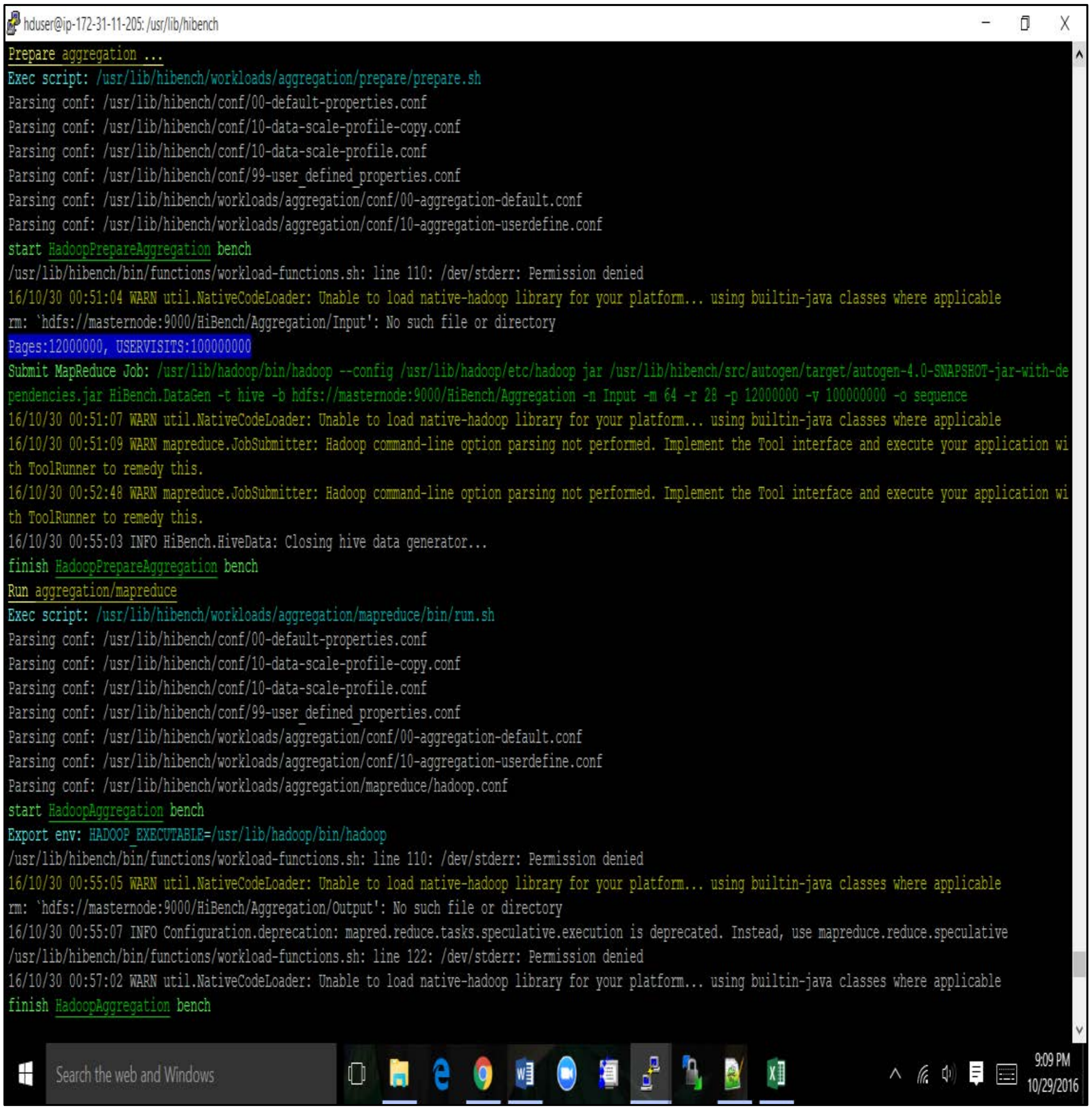
```
$<HiBench_Root>/bin/run-all.sh
```

For a specific workload in Map Reduce language,

```
$<HiBench_Root>/workloads/<workload_name>/mapreduce/bin/run
.sh
```

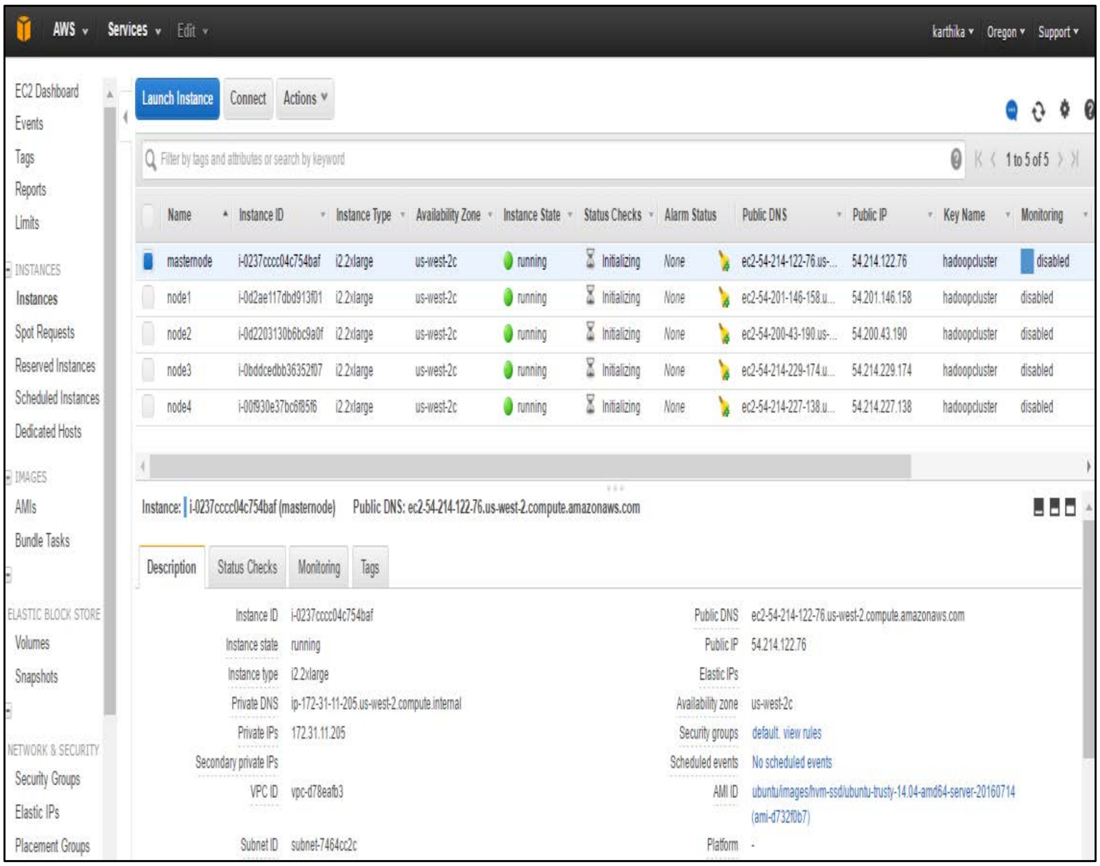
The report of the workload test runs is then added to 'hibench-report' file inside the /<HiBench_Root>/report directory.

1. Aggregation benchmark prepare and run script execution print:



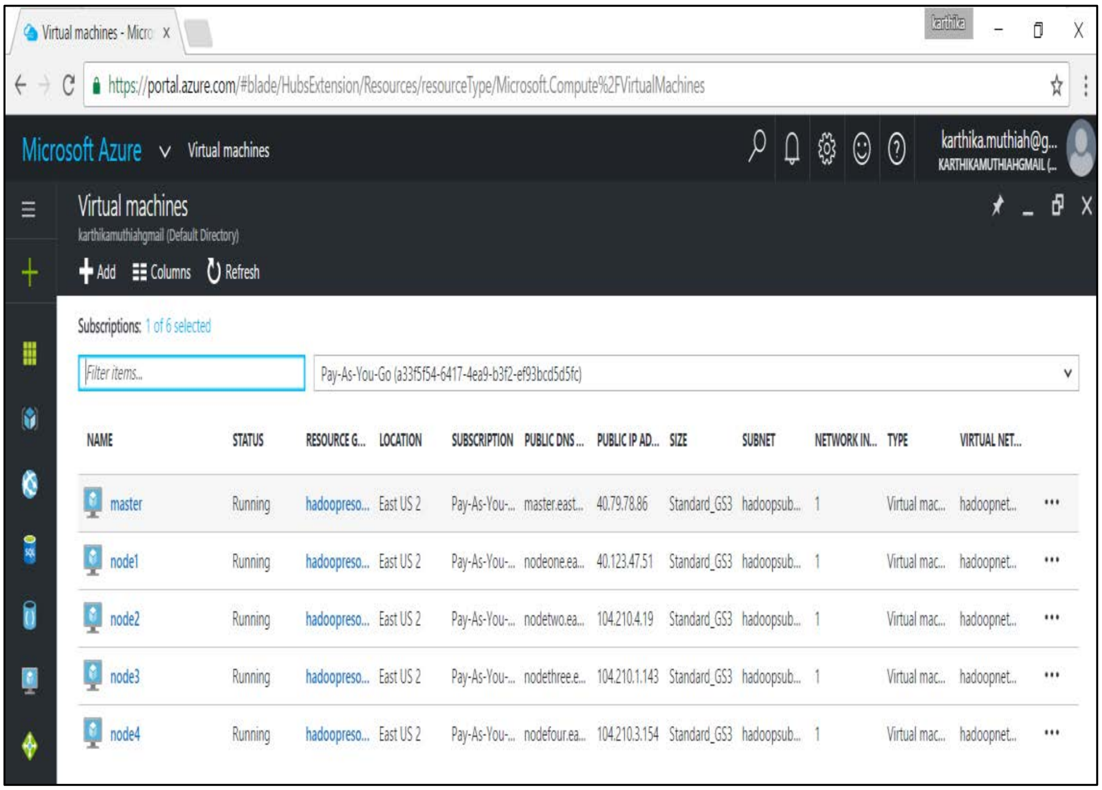
APPENDIX H

Amazon EC2 Screenshot



APPENDIX I

Microsoft Azure Screenshot



VITA

Karthika Muthiah received a bachelor's degree in Computer Science Engineering from Anna University in India in 2007, and aims to receive her Master of Science in Computer and Information Sciences from University of North Florida by April 2017. Dr. Sanjay Ahuja of the University of North Florida is Karthika's thesis advisor. Karthika worked as a Quality Analyst Engineer for 6+ years at ZOHO Corporation Private Limited, India for Networking based application. Her work experience involves working on technologies like Software Testing, Java, HTML, CSS, JavaScript, .Net application testing and development, MYSQL, and SQL Server databases. She currently works as Quality Assurance Intern for Black Knight Financial Services located in Jacksonville, Florida. Karthika is interested in working for a fortune 500 company where she can apply her knowledge and skills to the greatest possible level.