A Design of Heterogeneous Cloud Infrastructure for Big Data and Cloud Computing Services

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Abstract:
Cloud computing and big data are two core services in many organizations. Combining a big data platform, such as Hadoop, into the cloud architecture using virtualization technique will result in losing the performance benefit of MapReduce. Unique for the existing virtualized big data cloud, this work introduces an innovative cloud architecture called the heterogeneous cloud. In the heterogeneous cloud, the big data service is directly deployed onto the bare-metal machines without the help of virtualization. In order to implement such a heterogeneous architecture, we propose a primer architecture design with detailed solutions of potential technical issues and conflicts. With the maximal isolation of computing, network, and storage, the proposed heterogeneous cloud can reach the multifunction of big data and cloud computing with improved performance and energy efficiency.

Keywords: Heterogeneous Cloud; Big Data; Cloud Computing; Virtualization

1. INTRODUCTION

The last decade of practice has proved that centralizing available computing resources in an organization can reach a better performance and better IT management. With the development of virtualization technology, a popular buzzword – cloud computing has come to everywhere in everyone’s personal life. Software running as the hardware is the intrinsic feature of virtualization, which can create virtual machines on-demand of the end-users’ requests without extra investment of additional hardware. Cloud computing provides many benefits including “no up-front commitments, on-demand access, nice pricing, simplified application acceleration and scalability, efficient resource allocation, energy efficient, seamless creation”, etc. [1]. Many IT giants have published their cloud services including Amazon AWS (2005), Google AppEngine(2008), Microsoft Azure (2010).

Even though public cloud services have made promising advance to enable the end-users to access their personal data anywhere on any devices, the privacy concerns entangled with the data sharing makes public cloud services a double-edged sword [2]. Many developers and researchers started to focus on
private cloud to enhance the users’ privacy without losing the benefit of cloud services.

In [3, 4], the researchers already forecasted the upcoming big data era, where huge volumes of data will be created, stored, and transported over the Internet. By March 2014, 525 terabytes (TB) of data has been collected by the U.S. Library of Congress, which is about 5 terabytes per month [5]. International Data Corporation (IDC), a global IT research and consulting firm, claims that the “Digital Universe” measures 4.4 zettabytes (ZB, 1 zettabyte equals to 1 billion terabytes), and this number is expected to skyrocket to 44 zettabytes by 2020 [6]. We are now living in the age of big data. The data volumes needed to be processed on a day-to-day basis have well exceeded the storage and processing capabilities of a traditional single host.

A general comprehension of big data concludes in 3V’s, namely volume, velocity, and variety [7]. Many challenges arise such as big data storage, processing, and mining, which gain the attention of IT giants such as Google, Yahoo!, Facebook, IBM, Oracle, and Twitter. During the project Nutch [8], Google was simultaneously developing the Google File System (GFS) [4] and MapReduce [9, 10]. Those concepts were successfully implemented into the Nutch project, which later split into two projects, and the second became Hadoop [11–13]. Hadoop is a big data platform that provides both distributed storage (Hadoop Distributed File System, a.k.a. HDFS [12]) and computational capabilities (MapReduce [9]). Today many industries and higher education institutes are using Hadoop to meet their big data needs. The ecosystem of Hadoop is evolving everyday at a surprising speed.

Investing in both a cloud computing cluster and a big data cluster is typically costly, while virtualize the big data platform will also potentially lose the performance of Hadoop. Unique from traditional methods, this work is devoted to designing the new cloud architecture, called Heterogeneous Cloud, deploying directly the Hadoop cluster on the same infrastructure along with a private cloud platform.

The rest of this work is organized as follows. In section II, we describe the motivation of the heterogeneous cloud. In section III, the innovation of the heterogeneous cloud is explained in detail. Section IV states the challenges of constructing a heterogeneous cloud. Section V is devoted to a premier design of the heterogeneous cloud. The conclusion and future work is included in section VI.

2. MOTIVATION OF THE HETEROGENEOUS CLOUD

The major motivation for a heterogeneous architecture cloud cluster is to meet the on-going trend of cloud computing and big data. Traditional decentralized labor-intensive IT services are replaced by centralized resource-intensive cloud service. In addition, big data is no longer a business buzzword but currently a widely adopted industry standard. At the same time, many challenges arise catching the attention of researchers in multiple disciplines. How to build a platform with both cloud computing and big data service becomes an interesting and difficult question for many institutes.

As the name suggests a “heterogeneous cloud” proposed in this work is composed of a mixture of two critical components: cloud and big data. The cloud component is deployed as a private IaaS (Infrastructure-as-a-Service) facility. The big data component is a Hadoop cluster specifically for scientific large volume data processing and storage.

There are also alternative understanding of “heterogeneous cloud” [14, 15]. A general architecture is proposed in [15] to implement “heterogeneous computing” [16] in a cloud environment. The Nimbix Accelerated Computing Cloud [14] is a defining example to simplify users’ access to heterogeneous HPC (High Performance Computing) resources.
The novelty of the heterogeneous cloud in this work focuses on the deployment of big data service directly on physical servers along with the existing cloud service. The advantage of this design fashion is to maximally speed up the big data performance on hardware level, without the bottleneck of performance loss in virtualization [17–19].

2.1 Private IaaS Cloud

Cloud models can be categorized in different ways. In general, cloud infrastructures can be organized by its deployment model and service model.

2.1.1 Deployment Model

Based on its deployment the cloud clusters can be categorized into private cloud, community cloud, public cloud, distributed cloud, and hybrid cloud [20].

1. Private Cloud. A private cloud is a cloud platform built and operated solely for a single organization. Building a private cloud requires a significant level of knowledge and experiences in virtualization, networking, operating systems, and periphery technology. Building and maintaining a private cloud requires a profound budget and human works to be constantly invested. Once a private cloud is successfully built, it can be utilized to greatly improve the flexibility efficiency of an organization’s business and activities. In addition, a private cloud gives the organization the greatest level of privacy. A catalog of information is stored and managed inside self-run data center with flexible access control policies.

2. Community Cloud. A community cloud is comprised of infrastructure shared between multiple organizations or a community. The cost of construction is shared among the organizations in side the community. The scale of a community cloud is generally larger than a private cloud but smaller than a public cloud. Also the catalog of information is shared among every member inside the community. Even though less privacy for each member is maintained, the technical challenge to build and maintain the cloud infrastructure is mitigated by fusion of the expertise of the entire community.

3. Public Cloud. A public cloud infrastructure is built on a public accessible network environment. The scale of a public cloud is usually the largest. Usually, a public cloud infrastructure can only be constructed by IT giants such as Amazon, Google, and Microsoft. End-users only pay for the resources as they use in the cloud. Their information and data is transparent to the cloud vendor. Therefore, in a public cloud, privacy becomes a critical issue. The advantage of a public cloud is its scalability to meet the end-users’ need in peak workload seasons. Also it’s easy and inexpensive for an end-user to deploy the service needed.

4. Distributed Cloud. A distributed cloud infrastructure is composed of a distributed set of machine in different geo-locations. Normally, a distributed cloud ensembles the predecessor of cloud computing, namely grid computing.

5. Hybrid Cloud. A hybrid cloud is namely a combination of two components: the private cloud and the public cloud. The public cloud has an adequate amount of network and virtualization resources
to meet scalable needs of end-users. The organization owns a private cloud usually has a limited amount of resources for virtualization and end-user requests. During peak workload seasons, private cloud owners often choose to extend their services by employing a public cloud to work with its private cloud in order to release the workload pressure of the private cloud. After the peak seasons, they will reallocate all data and services from the public cloud back to their private cloud.

2.1.2 Service Model

We state the service motivation of the cloud infrastructure here. Generally, the services provided by the cloud clusters typically can be grouped into SaaS, PaaS, and IaaS. Not only do these models differ in the service provided but also the flexibility of cloud usage for end-user.

1. Software-as-a-Service (SaaS). SaaS provides the highest level of cloud computing service. The software is deployed in the cloud and delivered to end-users through cloud clients. The end-users can use the software without need to know how to install or maintain it. In SaaS, the end-users have the least level of flexibility. Typical examples include Google Drive, Microsoft Office 365, and Saleforce’s CRM solutions.

2. Platform-as-a-Service (PaaS). PaaS provides a platform on which users can deploy and run their programs. This platform typically provides operating system, programming environment, databases, and web server. The end-users can deploy their program on a PaaS cloud without the need to purchase the underling hardware and software. PaaS provides more flexibility than SaaS for the end-users. Typical examples include Google App Engine and Microsoft Azure.

3. Infrastructure-as-a-Service (IaaS). IaaS is the most fundamental form of cloud computing, in which end-users will be provided virtual machines to install their own operating systems. These virtual machines are organized by specialized software called a hypervisor, for instance KVM, Xen, and Hyper-V. The IaaS vendor typically charges the end-user for the amount of virtualization resources used. IaaS gives end-users the maximum level of flexibility since they can customize their application deployment from the operating system level. There are many mature IaaS platforms developed recently including Amazon EC2, Apache Cloudstack, Eucalyptus, IBM CloudBurst, and Openstack. Among them, Openstack has recently gained vast attraction, and its developer community thrives rapidly.

Among these three service models, we chose the IaaS as an ideal model for academic use, since researchers and students are the majority end-user on this cloud cluster. Typically, they will take care of their own needs for different software and application deployment environment. Using an IaaS platform gives them the maximum level of flexibility to satisfy their research and course needs.

2.2 Big Data

2.2.1 Implement Research and Teaching in Big Data

While the velocity of the data movement is increasing beyond an exponential speed, traditional storage and computing architectures cannot process them anymore. Recently, research in big data and massive
data management has been swift and violent. The ability to process big data and store it has become a business standard rather than a buzzword.

In this heterogeneous cloud infrastructure, we will build a Hadoop big data platform to perform a comprehensive study of topics related to data management and data mining. Most of research topics that we have studied previously are now facing the challenges of scalability and performance when moving into the big data era.

### 2.2.2 Provide Big Data Storage Service for Research in STEM Disciplines

Researchers in STEM disciplines are producing a huge volume of data every minute from their scientific data. In addition, this data doesn’t follow a fixed schema, except in rich types including text, image, video, and other multimedia types. They fit well into the concept of big data. Not only storing data, but also backing up, organizing, searching data, and knowledge discovering in massive data are all critical issues in which normal storage and computing solutions are not applicable.

The Hadoop platform is a mature platform, consisting of a Hadoop Distributed File System (HDFS) and MapReduce computing architecture, which has created many successful stories in both industrial and academic data management. The ecosystem of Hadoop provides a complete solution to support the data security and data integrity.

In this heterogeneous cloud cluster, we have designed multiple slave nodes to store their scientific data in Hadoop using HDFS’s built-in functions for fault tolerance and disaster recovery. Firewall monitoring and data backup on the cluster will be systematic and routine-based on the secured Linux firewall and automatic data replication in HDFS.

### 3. INNOVATION OF HETEROGENEOUS CLOUD

#### 3.1 Heterogeneous vs. Hybrid

In section II.A, we covered the definition of a hybrid cloud infrastructure, which is combining the private and public cloud. The need for a hybrid structure is to make a private cloud elastic to the peak service time by utilizing the larger resource pool in a public cloud.

The heterogeneous cloud infrastructure proposed in this paper doesn’t focus on expanding the scale of a private cloud, but makes the cloud multifunctional by blurring the borderline between cloud computing and big data.

Please note that the implementation of this multifunction is not by virtualizing a Hadoop cluster inside the cloud infrastructure. Instead, we directly deploy the Hadoop cluster onto the bare-metal machines. Each bare-metal machine in the cluster will be used both as a data node in the Hadoop cluster, but also a computing node (or slave node) in the Openstack cloud platform. We will show the detailed design in section V.
3.2 Multifunction Implemented by Bare-metal Deployment

Combining cloud computing infrastructure and a big data platform together has many benefits. The first is multifunction of the cluster. Within one cluster, we can provide both services, and also perform teaching and research tasks on the same facility.

3.3 Cost Efficiency

Budget issue is one of the first concerns for most of the small businesses and higher education institutes. Professionals and researchers are trying their best to lower the construction cost of a cloud cluster and big data cluster.

The innovation of a heterogeneous cloud is to expand the existing cloud infrastructure in a new dimension of big data. The big data component will share the same slave bare-metal machine without the needs to build a separate cluster specifically. Thus, one cluster with two major services provided will gain more attraction than two uni-functional clusters.

3.4 Privacy

In the heterogeneous cloud, the catalog of information and user data is stored in a private infrastructure. The information includes the meta-data of user accounts and profile information to access the cloud and big data platform, as well as the end-users’ experiment data and application source codes. By centralizing them into one cloud infrastructure behind a private organization firewall, the privacy of users are more protected then putting them on a public cloud data center, where the encryption only covers the data transportation rather than the data storage. Data privacy in a public cloud with an untrusted cloud vendor is still a central topic in the cloud computing community.

4. CHALLENGES OF HETEROGENEOUS CLOUD

While the innovation and benefit of a heterogeneous cloud seems promising, the challenges of implementing such a special complex infrastructure also arises in multiple disciplines. Because the two critical components cloud and big data platforms are sharing the same bare-metal machines in the cluster, it’s inevitable that they will bottleneck each other when both are requesting more resources in peak workload time. These conflicts will appear in multiple disciplines including network flow, storage I/O, data replication, and information security. We explain them in details as follows.

4.1 Network Flow Confliction

Both the big data platform and cloud platform extensively rely on the high-speed network (or high speed local area network) connection. It is especially critical for the big data platform because its typical tasks are map-reduce operations. In the reduce phase of a MapReduce work, the distributed data is collected
from multiple data nodes and transferred to the master node for final process. The typical volume of a Hadoop cluster is calculated in terabytes. Velocity of big data transportation is also astonishing in peak workload time. The more density in the big data cluster, the higher throughput of the network will be required.

For the cloud platform, the first concern is the network connection from end-users to the virtual machines. During busy network traffic time, the end-users will experience noticeable delay in their normal connections. Another important aspect is the fault tolerance operations in the cloud. For example, in the VMware cloud infrastructure, the vMotion model will transfer all the data of a virtual machine to a different bare-metal host to avoid the failure of critical service deployed on the original host. There will be constantly large volumes of data transferring in the cloud network.

4.2 Storage I/O Confliction

There are two majority types of storage discussed here: memory and secondary storage.

4.2.1 Memory Confliction

The cloud platform is actually a virtual machine farm. When each virtual machine (a.k.a. an instance) is created, the cloud platform will allocate a proportion of memory to the instance as the virtual memory. The memory allocated for cloud computing are typically from the memory of computing nodes (or slave nodes), rather than from the controller node (or master node) of the cloud cluster. Nevertheless, the finger daemons of the cloud platform still need a significant proportion of memory on the controller node.

For the big data platform, the master node (or name node) is running a critical task, namely JobTracker, and a metastore to control all the MapReduce jobs and keep a snapshot of every data block location in the whole cluster. The memory size needed by the name node is proportional to the data blocks on the slave nodes (or data nodes). Every one million data blocks will require 1GB of memory allocated on the name node machine. JobTracker will also require a significant amount of memory when there are many MapReduce tasks running.

4.2.2 Secondary Storage Confliction

Secondary storage in the heterogeneous cloud refers to the storage device with large volume and lower speed throughput, such as different kinds of hard drives. Hadoop will consume the majority proportion of the secondary storage on the bare-metal machines. In the file system of Hadoop, namely Hadoop Distributed File System (HDFS), the data is shredded and distributed over the data nodes in the cluster. Typically, there are 3 copies of the same data, one on the original host, one off the host, and one off the rack. This also enhances the fault tolerance of HDFS.

Each virtual machine in the cloud platform also needs an allocation of secondary storage to build its virtual hard drive. When the scale of the cloud is growing bigger, the need for more space is becoming greater. Also, the end-users often prefer higher speed storage, such as Solid-state Drives (SSDs), to be their virtual hard drives.
4.3 Heterogeneous Data Replication

Periodically backing up data is the key to prevent disaster in a data center. Traditional data backup follows an incremental daily fashion; but most recently, more and more organizations have switched to real-time backup [13, 21, 22]. A secondary copy of data is sent in real-time to a different repository to reduce the risk of losing data of a single day. For the big data platform, the most important part for data replication is the metastore in the name node. In order to let the MapReduce jobs run efficiently, the name node keeps a snapshot of every data block in a main-memory data structure, which is the metastore. Failure on the metastore will lead to loss of the entire data read capability. Therefore, a real-time copy of metastore is often sent to the secondary name node in the most recent version of Hadoop. Another important aspect of the big data platform is that HDFS can automatically create an off-the-rack data copy and send to an off-site rack cluster; however, the data replication in a large volume scale can easily increase the burden of network traffic. This is the same situation faced by the cloud platform.

4.4 Network Security

Privacy control is always one of the top concerns in a cloud environment. For the cloud platform, there needs to be a well-defined access control policy to protect users’ data from unauthorized access.

In the big data platform, only the name node can read data from the data nodes. This makes the big data platform vulnerable to single-point failure risk. Often, name node data is backed up in real-time to a secondary name node. But protecting the information security and network security of the major name node is still important.

5. DESIGN OF HETEROGENEOUS CLOUD

In this section we discuss in detail about the design of the proposed heterogeneous cloud. Two aspects of the heterogeneous cloud are considered in the design phase, namely the hardware layout and the service layout. The hardware layout includes the hardware infrastructure of the heterogeneous cloud architecture and the interconnection design of the infrastructure. The service layout includes the software deployment, storage design, and network design.

5.1 Hardware Layout

Without loss of generality, we propose a detailed design of a single cluster composed of one rack of servers (or a Pod of servers), and illustrate how this rack of servers can be connected to a hybrid network with double-layer firewalls. Any larger scaled heterogeneous cloud architecture can be generalized from this design by duplicating more racks of servers with similar network topology. In addition, for a heterogeneous cloud with multiple Pods, the administrator can also logically divide them into different zones according to different locations logically or physically.
5.1.1 Cluster Layout

The overview of one Pod of the heterogeneous cloud hardware layout is illustrated in Figure 1. The Pod is comprised of six commodity servers, one RAID array server, one high-speed switch, and two PDUs (Power Distribution Units). The numbers of servers can be variable on the users’ needs. We only use a smaller number in considering the simplicity of the distributive work.

The private IaaS cloud and the Hadoop cluster are deployed on the six commodity servers. Among them, we include one Dell PowerEdge R420 server and five Dell PowerEdge R520 servers. The R420 server is used as the master node for both the cloud platform (as the controller node) and big data platform (as the name node). The R520 servers are used as the slave nodes in cloud platform (as computing nodes) and big data platform (as data nodes). In order to deploy both platform onto the same bare-metal server, the storage devices need to be specially partitioned, which we will discuss in section V.B.5).

The RAID (Redundancy Array of Inexpensive Disks) array server at the bottom of the Pod in Figure 1 is independent of the two service platforms in order to perform data replication and implement disaster recovery. In the realistic practice, the heterogeneous cloud can perform off the Pod data replication between RAID servers in different data centers.

Each server is equipped with dual network interface cards (NIC’s) in order to split the network traffic of big data and cloud computing. We also include a Cisco high-speed layer-2 switch into the Pod in consideration of there is no specific needs of layer-3 routing (see V.D). But the heterogeneous cloud requires at least one high-speed switch in each Pod, since the big data platform and the cloud platform will both be “hungry” of the network bandwidth when they both need to transport a large amount of data.
data. There is an option to include a second high-speed switch as a backup switch to guarantee the high availability for critical tasks.

PDUs are included as a common periphery accessory. We also assume the location of the Pod is within a data center with UPS (Uninterruptable Power Supply) units.

Figure 1 also illustrates the network design of the heterogeneous cloud, which will be covered in section V.D.

5.1.2 Power Consumption

Power consumption is receiving more and more attentions in the large data center environments. Reduction of the energy cost is also a major consideration in the hardware design of the heterogeneous cloud. The two service platforms are well combined into a single cluster infrastructure, which will significantly improve the energy efficiency compared with other separated service platforms. In addition, in quoting the Dell PowerEdge R420 and R520 servers, we adopted the Intel Xeon V2 family CPUs to increase the energy efficiency with greater performance. Even with normal cooling systems, the Pods of the heterogeneous cloud will exhaust less heat.
5.2 Service Layout

The heterogeneous cloud is a combination of both a cloud computing platform and a big data platform. The most significant feature is the big data platform shares the same bare-metal machines with the cloud platform.

Figure 2 illustrates the general service layout of the heterogeneous cloud. The service requests from the web will be logically split into cloud requests and big data requests, both of which are transferred through the high-speed networking devices in the Pod. In addition, the computing and storage resources are also logically partitioned for cloud and big data usage, which is covered in section V.E.

5.2.1 Cloud Platform

The cloud platform is to create a private IaaS environment as stated in section II.A. There has been many mature enterprise level products on the market for an IaaS cloud including VMware vCloud suite, Eucalyptus, Cloudstack, Openstack, and etc. The VMware vCloud suite is a complete and robust solution for large enterprise virtualization environment widely used in business and higher education. However, the cost for the license of the vCloud is significantly higher than other open source IaaS products. In addition, the rapid growth of open source cloud platforms brings more community developers to devote to improving their functionality and robustness. Among them the Cloudstack and Openstack draw more attention than other competitors. We consider the convenience of deployment, management, and hardware compatibility and finally choose the Openstack as the IaaS platform for the heterogeneous cloud.

We employ the most recent release of Openstack version 2014.1 (a.k.a. Icehouse) [23]. Currently the Openstack is composed of seven core components including Swift, Glance, Nova, Horizon, Keystone, Quantum, and Cinder. We describe these components in turn.

Swift is the object store that provides the object storage. Glance is the image manager for virtual disk images, which will be used to create virtual machines in the cloud. Nova is the virtual server manager in control of all the virtual machines. Horizon is a web-based dashboard for the administrator and end-users to control and monitor the virtual machines. Keystone provides the key management service in a cloud. Quantum is the virtual network manager providing “network connectivity as a service” in Openstack. Cinder manages the persistent block storage used by virtual machines.

5.2.2 Big Data Platform

The big data platform we chose is Hadoop. There are multiple distributions of Hadoop provided through the big data service vendors such as Cloudrea, IBM, Amazon, Hortonworks, etc. Cloudrea also provides several versions of Hadoop with a well-polished web user interface to manage the Hadoop clusters. Without the risk of involving additional license costs, we chose the original distribution of Apache Hadoop [24] to deploy on the Heterogeneous cloud. A typical Hadoop cluster consists of the following components [17]:

Common Components. A set of common modules and interfaces for distributed file systems and general I/O.
Avro. A remote procedure call (PRC) and serialization system which uses Javascript Object Notation (JSON) for data definition and protocols, and performs data serialization in a compact binary format.

HDFS. Hadoop Distributed File System, which manages large volumes of data on clusters of commodity servers. It is a scalable and portable file system written in Java. From Apache Hadoop version 0.23, a new MapReduce runtime is introduced, called MapReduce2 (MRv2) which is implemented on a new system called YARN (Yet Another Recourse Negotiator). YARN provides improved resource management and job scheduling/monitoring for distributed daemons in Hadoop.

Pig. A data flow language and execution environment for large data exploration.

Hive. A distributed data warehouse built on HDFS. Hive provides a SQL like language, called HiveQL, which can translate structured query language into MapReduce jobs to achieve simplified big data management.

HBase. A distributed column-store NoSQL database that uses HDFS as its underlying storage.

ZooKeeper. A centralized service that allows distributed processes to coordinate with each other through a shared hierarchical name space. Zookeeper provides high throughput, low latency, and highly available access to the nodes within its administration.

Sqoop. A convenient tool for data ingress/egress between HDFS and relational databases.

5.3 Operating System

Based on the cloud platform and big data platform chosen, we employ Ubuntu Server Linux 14.04 LTS as the operating system on each server. Ubuntu Server LTS has been widely used in the industry and higher education. Compared to CentOS (Community Enterprise Operating System), which is a Red Hat flavor of Linux, the software repository of Ubuntu Server 14, which is more up-to-date; there are many tools for Ubuntu Server Linux that the administrator can utilize to rapidly deploy Openstack and Hadoop.

5.4 Network Design

To solve the network flow conflict stated in section IV.A, we created two VLANs (Virtual Local Area Network) within each Pod to split the network flows. They are denoted as the big data VLAN and the cloud VLAN. Each VLAN is configured differently confusing on their different needs. The advantage of using VLAN over subnet is that VLAN can be implemented using a layer 2 switch \[25\] instead of a layer 3 switch to lower the budget.

In the big data VLAN of a Pod, we have one name node and five data nodes. Again, the number of data nodes designed here is for the demonstration purpose and thus can be easily adjusted to a larger number thanks to the scalability of Hadoop. For such a limited number of bare-metal machines, we create a /24 VLAN on each Pod to host a maximum 256 IP addresses. Since only the name node can read data from the data nodes, making data nodes publicly accessible is not necessary. Therefore, the IP addresses in the big data VLAN will be internal IP addresses such as 192.168.x.x/24. To access the master node of the Pod, end-users can use the cloud VLAN IP address on the name node, which is publicly accessible only through VPN (Virtual Private Network). Also, access control rules will be implemented on the network switch to block off-the-rack traffic to directly access the data nodes.
In the cloud VLAN, the hosts are not only the bare-metal machines, but also the addresses virtual machines. There are two models to access the IPs in Openstack. The direct model is to create virtual machines in the same VLAN with the bare-metal machines, so that users can directly access them once they are connected to the cloud VLAN. The other mode is to use the software defined network (SDN) function embedded in Openstack to map the virtual machines with internal addresses to connect with the end-users. For management convenience, we adopt the direct network model for virtual machines and create a /20 public VPN accessible VLAN in order to allocate an adequate space for virtual machines.

In the cloud platform, most of the cloud traffic is in connection with the virtual machines on the computing nodes (slave nodes), rather than the controlling node (master node). For the big data VLAN, the inbound and outbound traffics are through the cloud address of the name node (master node), and MapReduce traffics are isolated to the big data internal network. In such a manner, the traffics of big data and cloud computing are well isolated with minimum conflicts.

5.5 Storage Design

For secondary storage, as illustrated in Figure 3, the master bare-metal machine is equipped with two high-speed hard drives in combination for RAID-1. Each slave bare-metal machines is equipped with 6 high-speed hard drives, in which two for RAID-1, and the other 4 for JBOD (Just a Bunch Of Disks). The RAID-1 array on the master machine is to host the operating system with a shared partition for both the cloud platform and the big data platform. On the slave machine, we isolated the secondary storage for cloud computing and big data. The operating system and Openstack storage will be hosted on the RAID-1 array, while the big data storage for Hadoop will be hosted on JBOD. The Openstack concatenates all the storage in the Pod through the network file system (NFS). In order to make sure the end-users’ data are protected on each slave machine, we created RAID-1 for each of their share in the NFS. However,
the file system of Hadoop, namely Hadoop Distributed File System, is embedded with data replication function, therefore, RAID cannot help any in the big data platform. Instead, we build the four hard drives into JBOD to maximum utilize the space on the secondary storage devices.

For memory storage, each slave bare-metal machine is equipped with at least 64GB high-frequency memory. The master machine is designed with 32GB to meet the requirement for the name node in Hadoop and the controller node in Openstack. The JobTracker in Hadoop and the controlling finger daemons of Openstack will run on the master machine. In practice, the administrator can flexibly increase the memory size of the master machine in case memory-bound tasks are observed in the heterogeneous cloud.

5.6 Data Replication and Network Security

For big data security, all data transportation will be encrypted by enabling Kerberos in the Hadoop cluster. In addition, all the data entering the HDFS of the heterogeneous cloud infrastructure will be shredded and split over the JBOD arrays on the data nodes. The only method to read data from HDFS is through the name node. This makes the Hadoop cluster vulnerable to single-point failure attacks. Therefore, we will make the RAID array server on the bottom of the Pod in Figure 1 to be the secondary name node for a backup in real-time. The RAID array server also backups other critical data in the cluster manually controlled by the administrator.

For the cloud data security, since the end-users’ data are stored in the virtual machine images, we design on each slave machine to use RAID-1 to backup those images. Openstack also provides data backup functionality to backup the cloud data from one Pod to another Pod within the private cloud or even to a public cloud. A complete set of access control lists (ACLs) will be implemented on the Cisco switch to ensure the data security for virtual machines and the Openstack platform.

6. CONCLUSION AND FUTURE WORK

In this work, we proposed an innovative model in cloud computing to include the big data service in a specially designed cloud infrastructure, called the heterogeneous cloud. To avoid the performance loss of the big data platform in a virtualized environment, we designed the architecture of the heterogeneous cloud to directly deploy the Hadoop platform onto the bare-metal machines shared with the Openstack platform. Due to this high service density design, many technical difficulties arise such as the network flow conflict, storage conflict, data replication, and network security. To overcome these issues, we proposed a unique design to maximally isolate the cloud platform and the big data platform in network and storage. The benefits of the heterogeneous cloud include improved energy efficiency, increased functionality, greater performance, and lower costs.

Future work includes extensive experiments to perform on the heterogeneous cloud to test the performance, energy efficiency, and scalability. We will also compare the Openstack and Hadoop with other competitors in cloud computing and big data platforms.
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- Infrastructure, Platform, Application, Business, Social and Mobile Clouds
- Innovative Cloud Applications and Experiences
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