Cloud Computing: Architecture and Operating System

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***Abstract*—Nowadays, cloud computing has become the center of attention in the IT world. It provides powerful computing services to individuals and organizations via the Internet, and enables them to access a pool of shared resources such as storage servers and applications. Businesses of all sizes are adopting cloud computing at an increasing rate as it provides them with great benefits like cost efficiency, since they do not actually have to buy the hardware and software resources, but simply pay per use. The cloud architecture consists of different levels in which each level gives the user additional control. Furthermore, a good operating system is crucial, and traditional operating systems cannot attain all the requirements of the cloud. For this reason, special operating systems need to be designed that can handle the demands of the cloud. This paper will discuss the cloud architecture and operating system.**

Keywords: cloud computing, cloud service models, cloud deployment, cloud OS.

I. INTRODUCTION:

Cloud computing is one of the popular and most talked about topics at the moment. It portrays the future of the information age. Cloud computing is an Internet-based computing model in which applications and data are not stored locally in a person's computer, but rather in remote servers and can be accessed through the Internet. Although the term "Cloud Computing" seems relatively new, the concept behind it is not new at all. It began in the 1950s when large corporations, government organizations and schools installed large-scale mainframe computers, allowing multiple users to physically access the computer from multiple terminals, in addition to shared central processing unit time [1]. Ever since then, cloud computing has evolved through a number of phases. Today, cloud computing provides a new way to design and manage computing resources. One has to simply create an account with a cloud service provider (CSP) such as Microsoft's Windows Azure or Amazon Web Services, in order to start developing and deploying application systems into the cloud [2]. Cloud service providers offer network services, infrastructure and applications in the cloud to both companies and individuals [3]. The main objective of cloud computing is to improve the utilization of distributed resources and join them to accomplish higher throughput, and be able to solve large-scale computation problems. Cloud computing deals with scalability, interoperability, virtualization, delivery models and quality of service [4]. Moreover, it provides a set of great advantages like mobility, cost efficiency, storage, backup and disaster recovery. These advantages are the reason as to why an immense number of people are migrating to IT solutions that include cloud computing. Recent statistics show that by 2016, the global revenue generated from public cloud computing services, is expected to grow from 10.27 billion U.S. dollars in 2012 to more than 200 billion [5].

This paper is organized as follows. In section II we explain the architectural components of the cloud. Then, we discuss the operating system of the cloud in section III. We finally conclude in section IV.

II. CLOUD COMPUTING ARCHITECTURE:

The cloud computing architecture is divided into two main sections: Front End and Back End. The two sections are connected to each other through a network, usually the Internet. Front End can be an end –user, client, or any application which is using the cloud services [12]. Back End is the cloud of the system and has the cloud computing services like multiple computers, servers and data storage. The cloud has a central server that monitors the traffic and manages the system and client demands [4]. The demand of resources is not always consistent from client to cloud. Therefore, server virtualization techniques are applied in which all physical servers are

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virtualized and can run multiple servers with the same or different applications [12].

A. Layers and Services of Cloud Computing:

Figure.1 bellow illustrates the different layers of cloud computing architecture.

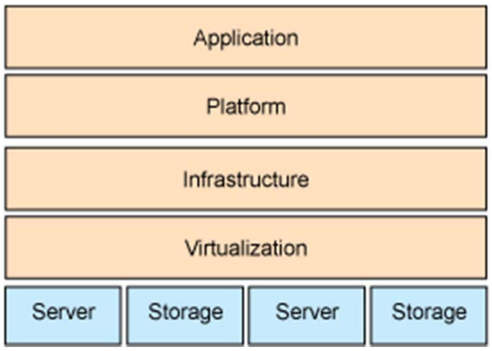

Figure 1. Layers of cloud computing architecture.

The cloud computing architecture has three distinct layers that together create the cloud environment. These layers are:

1. Infrastructure as-a-Service (IaaS):

IaaS provides the infrastructure as a service to its customers. The client does not need to buy the required servers, data center or the network resources. Customers are able to achieve a much faster service delivery with less cost [13]. Moreover, customers control and manage the systems in terms of the operating systems, applications, storage, and network connectivity, but do not themselves control the cloud infrastructure [14]. The low-level resources cannot be utilized on their own, and thus are typically exposed as part of a "virtualized environment" i.e. hypervisors [15]. IaaS offers physical or virtual machines as well as resources such as file-based storage, firewalls, IP addresses, virtual local area networks (VLANs), and software bundles. IaaS cloud providers supply these resources on-demand from their large pools of resources installed in data centers. Infrastructure as a Service is also referred to as Hardware as a Service (HaaS) [12].

2. Platform as-a-Service (PaaS):

In the PaaS model, cloud providers supply customers with a computing platform typically including the operating system, execution environments, database, and web servers. The consumer will not manage the operating system and network, and there might be limitations as to which applications can be deployed into the cloud [14]. Application developers can develop and run their software solutions on a cloud platform without the cost and complexity of buying and managing the underlying hardware and software layers [12]. PaaS automatically scales the underlying hardware and storage resources to match application demand such that cloud users do not have to allocate resources manually [12].

3. Software as-a-Service (SaaS):

SaaS may also be referred to as Application Clouds and is the most basic cloud service model. It provides applications and services using a cloud infrastructure or platform, rather than providing the cloud features [15]. In the SaaS model consumers pay to access and use an application or service that is hosted in the cloud [14]. The cloud users do not manage the cloud infrastructure and platform on which the applications are running. This eliminates the need for clients to install and run applications on their own computers, and thus simplifying the maintenance and support. Cloud applications differ from other applications in scalability. This is done by copying tasks onto multiple virtual machines at run-time to meet the changing work demand. The load balancers distribute the work over the set of virtual machines. This process is transparent to the cloud users [12].

All of the service models mentioned above are priced on a pay-per-use basis. This is of great benefit to individuals and organizations who cannot afford purchasing, installing and maintaining the required services [4].

Table 1. shows examples of the services provided by the SaaS, PaaS and IaaS models and which users benefit from those services [16]:

TABLE 1.

Service Model:	***Who uses it:***	***Services:***
SaaS	Business users	• E-mail, blog, wiki • Productivity tools (Office) • CRM • Website testing
PaaS	Developers and deployers	• Service and application testing • Development • Integration and deployment • Database management
IaaS	System Managers	• Virtual machines • Management • Message queues • Networks • CPU, memory, storage

B. Cloud Computing Deployment Models:

Cloud computing deployment models are divided into four categories, and each model represents a specific type of cloud environment with certain characteristics that support the needs of the cloud users [14]. The deployment models are as follows:

1. Private Cloud:

A private cloud refers to internal services of a business that is not available for regular people [13]. The cloud infrastructure is deployed, maintained and operated for a specific organization [12]. Private clouds offer services to a specific group of people behind a firewall. The major advantage of private clouds is that they make managing security, maintenance and upgrades easier. Moreover, they provide more control over the deployment and utilization since resources and applications are managed by the organization itself [13]. The operation may be in-house or with a third party on the premises [12].

2. Public Cloud:

A public cloud is a type of cloud hosting in which the cloud services are delivered over a network which is open for public usage [17]. Public clouds are not as secure as the other cloud models since the applications and data on the public cloud are more prone to malicious attacks [13]. Nevertheless, one of the main benefits of public clouds is the almost unlimited scalability. The resources are offered on demand so any changes in the level of activity can be handled very easily. This in turn brings with it cost effectiveness [18]. From the technical perspective, public and private clouds have little to no difference in the structural design. They however, differ in the level of security of various services offered to the cloud user [17].

3. Hybrid Cloud:

The cloud infrastructure is comprised of a number of clouds of any type. This can be a combination of private and public clouds. The clouds have the ability to move data and applications from one cloud to another [14]. The advantages of multiple deployment models are found in hybrid clouds. A hybrid cloud enables users to increase the capacity or the capability by aggregation, assimilation or customization with another cloud package or service. In a hybrid cloud, the resources are managed and provided either in-house or by a third party [17].

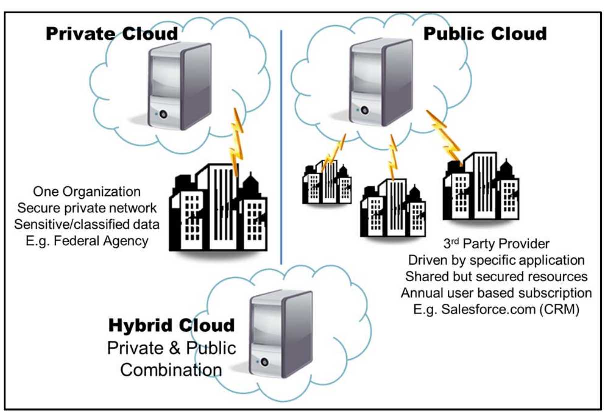

Figure 2. Private, Public and Hybrid clouds

4. Community Cloud:

In this type of cloud deployment model, a number of organizations that belong to a specific community (i.e. banks) share the infrastructure of the cloud. It is a multi-tenant setup that is shared among multiple organizations that belong to a certain group that has the same cloud requirements. The community members generally have the same privacy, security and performance concerns. The main goal of these communities is to achieve their business related objectives. A community cloud may be internally managed or by a third party on the premises [17].

Table 2. shows the cloud services and deployment models offered by some of the currently popular cloud providers.

TABLE 2.

Cloud Service Provider:	***Offered Service Models:***	***Deployment Models Available:***
Amazon Web Services	• Infrastructure as a Service (IaaS)	• Hybrid Cloud • Private Cloud • Public Cloud
Windows Azure	• Platform as a Service (PaaS) • Software as a Service (SaaS)	• Private Cloud
IBM Cloud	• Infrastructure as a Service (IaaS)	• Hybrid Cloud • Private Cloud
OpenShift	• Platform as a Service (PaaS) • Infrastructure as a Service (IaaS)	• Hybrid Cloud • Private Cloud • Public Cloud
Oracle	• Platform as a Service (PaaS) • Infrastructure as a Service (IaaS) • Software as a Service (SaaS)	• Hybrid Cloud • Private Cloud • Public Cloud
Microsoft Cloud for Government	• Software as a Service (SaaS) • Platform as a Service (PaaS)	• Community Cloud

III. THE CLOUD OPERATING SYSTEM:

An operating system (OS) is the software that manages all of the computer's hardware resources as well as software. The operating system is critical in supporting the underlying complexity of well-managed cloud computing resources. Traditional operating systems such as Mac OS X or Windows 8 are designed to manage only individual machines. A cloud operating system however, is especially designed to manage large collections of infrastructure as a seamless, flexible, and dynamic operating environment. It transforms the collection of infrastructure of an entire datacenter into a single and powerful compute plant whose resources are allocated instantly and dynamically to any application that requires the resources [6]. A cloud operating system (Cloud OS) provides an additional set of services to the traditional operating systems that offer administrative access to resources in the cloud including allocating and deallocating virtual machines, dispatching and migrating processes, setting up inter-process communication, etc. It also includes software support for the independent scaling and opportunistic deployment of distributed applications. In addition to a set of network-based interfaces that enable applications to query the management system and control the cloud resources [7].

A. The Cloud OS Requirements:

A cloud operating system must satisfy the following requirements to ensure efficient and reliable use of the cloud:

- A cloud operating system should be able to continue its operation in spite of loss of nodes, entire clusters, and network partitioning. In order to continue operation in such conditions, the cloud OS must have mechanisms for quickly detecting the failures and enacting appropriate measures [7].

- The cloud OS must provide an abstraction of the cloud as a logical system beyond the individual components of hardware from which it is built. Thus, it should provide an interface that hides the fact that separate nodes are involved in its low-level operations, and what those operations are [7].

- The cloud OS management system must be decentralized and scalable such that no human intervention is required to expand the cloud resources when needed. Moreover, it should have little overhead per user and per machine, and be cost effective [7].

- Each application should not be required to create essential functions like virtual machine monitoring, scheduling, security, power and memory management. The operating system needs to provide such services instead. [8].

- Virtualization is fundamental to cloud computing. An operating system therefore must be able to manage and control not only virtualized physical servers but also virtualized resources such as memory, networks, storage and software [8]

- For any organization using the cloud, security is a critical aspect to ensure protection for the assets. The cloud environment can be greatly distributed and may involve dynamically connecting and disconnecting from a large number of internal and external systems and assets. Thus, the cloud operating system must have an integrated management ability that can track how all resources are being used. This ability needs to override weak links in the overall system to ensure that the security will satisfy and meet the organization requirements [8].

B. The Logical Architecture of the Cloud OS:

Figure 3. illustrates a proposed cloud operating system with multiple layers and the components in each layer are specified in their respective layers as well. The Cloud Object is defined as a batch of local OS processes running on an individual node, which are joined together and assigned locally a random identifier of appropriate length to reduce the risk of system-wide ID collisions. A Cloud Process (CP) is a collection of cloud objects that implement the same (usually distributed) application. The small number of CPs that controls physical allocation, accounting, access control, and measurements of resources is referred to as the Cloud Kernel Space. User Applications are the CPs that are executed in the user space directly by users. The Cloud Libraries on the other hand, are the CPs that are typically called upon by applications and other libraries. Applications can interface with libraries and kernel CPs over the network through a set of standard interfaces called Cloud System Calls. The hypotheses stated above place very few limitations about the features that the underlying cloud hardware is expected to provide [10].

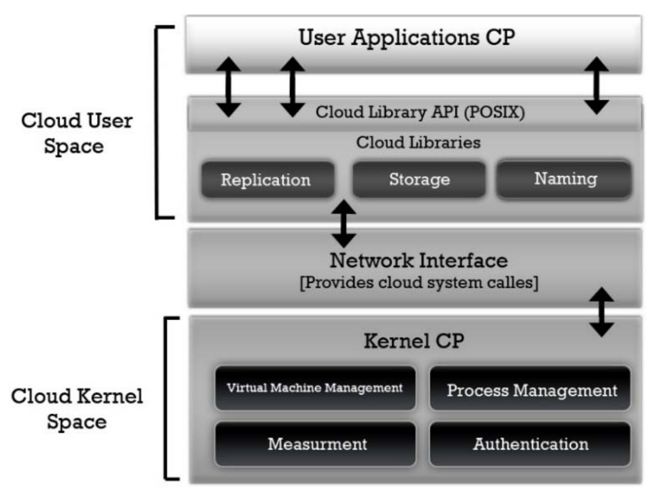

Figure 3. Logical architecture of cloud OS [7].

Essentially, the ability to execute the cloud kernel processes, along with the availability of suitable trust credentials, is an adequate condition for a node to be part of the cloud. In addition, a limited access to the cloud abstractions and interfaces is achievable from machines that belong to administrative domains other than that of the cloud provider, with the possible restrictions due to the extent of the management rights available there. All objects in the cloud user space expose a cloud system call handler to catch signals from the cloud OS, that is, they can be accessed through a network-based interface for management purposes. The process management and virtual machine management kernel CPs maintain the association between object names and their network address and port, and the naming library makes the resulting information available throughout the cloud. Moreover, the naming library keeps track of the link between user application CPs and the objects that they are composed of. The authentication kernel CP grants and verifies the access rights necessary for all management operations. Measurement kernel CPs are constantly active in the cloud, and operate in both on-demand and background modes [10].

C. *Linux: The Operating System of the Cloud:*

The Linux operating system was not able to shine in the desktop world however; it is currently the go-to operating system for the cloud, and upon which the largest cloud infrastructures in the world have been built on. Google's Chris DiBona said "Every time you use Google, you're using a machine running the Linux kernel" [9]. Ross Turk, vice president of community at Inktank Inc., also said "Linux has already conquered the public cloud. With the exception of Azure, all of the other dominant public clouds run both compute and storage on Linux. And for virtual machines running in the cloud, it's all Linux, including Azure" [11]. Linux has a set of characteristics that makes it very desirable among the cloud computing vendors. These characteristics are as follows:

a) *The Architecture of Linux:*

The Linux kernel supports a great degree of componentization and is incredibly adaptable to computing environments of all shapes and sizes. This is particularly important in highly customized, scale-out cloud platforms that need to run on a diverse collection of commodity hardware, networking and storage. Linux is an open source operating system, i.e. its source code can be modified. This is of great benefit to cloud service providers as they can customize the kernel to meet their specific needs and hardware [9].

b) *The Linux Compatibility:*

There is a large number of Linux compatible and certified applications available. This enables users to choose from a vast range of options to satisfy their specific workload needs. Due to Linux's quality and open source nature, many developers of different types of applications choose Linux for the deployment of their applications. For this reason, Linux is the number one choice for cloud providers as they benefit from the wide range of applications available to the Linux platform [9].

c) *Cost of licensing:*

Linux is not always free in the financial sense of the word. Most organizations and governmental production deployments are commercially licensed and supported. There are however, non-commercial distributions of Linux. Since creating a cloud infrastructure that consists of more than thousands of licensed nodes is costly, cloud providers can choose any of the non-commercial distributions of Linux [9].

d) *Power Efficiency:*

Due to its usage in small, power sensitive devices. A great deal of research in lowering total power consumption has been done on Linux. Many efforts have been made to make Linux more power efficient than other operating systems. These efforts combined with the power saving efforts within cloud data centers have helped lower the total solution cost for cloud customers [9].

e) *Virtualization:*

Virtualization involves the ability to abstract the operating system or application instances from the underlying cloud platform. Linux users have a variety of virtualization technologies ranging from the hypervisors that enable virtualization, to the management tools that allow the virtualized resources to be efficiently assembled and used. In addition, Linux can serve both as a host for virtualized instances or as a guest itself [9].

f) *Staffing:*

Organizations need to consider how their existing skillsets map to the current technologies, and the ability to recruit those skills from the general market in the future. Managing and developing for Linux are common skills that do not require staff re-training. With Linux, customers can deploy to the cloud and avoid expensive re-training for system administrators and developers [9].

IV. CONCLUSION:

There is no doubt that cloud computing is the present and future of the IT industry. Cloud computing imposes great benefits that makes it one of the most talked about topics in recent years. Those seeking cloud IT solutions need to understand the different cloud service and deployment models available and which one best suits their needs. In order for cloud consumers to benefit from the cloud capabilities, special operating systems need to be designed that can handle the great demands of the cloud. Linux has become the dominant cloud operating system and the first choice for many cloud providers due to its many advantages.

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