DOI:10.3969/j.issn.1673-5188.2017.04.003
http://kns.cnki.net/kcms/detail/34.1294.TN.20171108.1011.002.html, published online November 08, 2017

HCOS: A Unified Model and Architecture for Cloud Operating System

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Abstract

Currently, Infrastructure as a Service(IaaS) and Platform as a Service(PaaS) platforms play a role as a cloud operating system(COS). They are separated from each other in resource management, which may cause inconsistent resource status and result in the decrease of performance. Moreover, heterogeneous resources are not managed well in existing cloud computing platforms. Referring to the theory of operating system, we propose a unified architecture model of cloud operating system, which has six layers corresponding to the layered architecture of legacy operating system. Based on this architecture, a new cloud operating system called Hua-Cloud Computing System(HCOS) is realized. In HCOS, the hybrid resources are managed in a unified way. This method improves the unified scheduling capability of heterogeneous resources and eliminates the problem of resource status inconsistency. The main characteristics of HCOS are introduced and two typical applications are illustrated in this paper.

Keywords

cloud computing; IaaS; PaaS; cloud operating system

1 Introduction

Cloud computing is an emerging business computing model. It is seen as the third IT revolution following the personal computer revolution and the Internet revolution. It brings a fundamental change in lifestyle, production methods and business models. It integrates or segments physical resources into resource pools by using virtualization technology. Then a variety of applications could use virtualized resources according to their actual demands. Classically, cloud computing systems provide three main categories of cloud computing services: Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS). The supporting system of the three types of cloud services is cloud computing platform, which is usually built above large data centers.

The core software of cloud computing platform is cloud operating system (COS), which is also called cloud platform. COS is a set of control systems for applications running in the cloud environment. It works on hardware and legacy operating system, manages and schedules all resources, provides fundamental resource services and operation environments for cloud applications. From a technology perspective, COS defines a set of standard interfaces between cloud resources and cloud applications, ensuring the efficient and standardized use of resources. COS is also built with a set of efficient task and resource scheduling models, used to decide how to efficiently manage and allocate system resources.

Existing cloud operating system is divided into two parts: PaaS and IaaS. The two parts are completely independent and could be deployed or used respectively. The IaaS manages computing, storage and networking resources and provides basic resource services to the PaaS or to users directly. The PaaS supports the full life cycle management of cloud applications, including coding, testing, deployment and maintenance. It could be built on a traditional data center or on an IaaS-based cloud data center.

IaaS plus PaaS is a typical and complete cloud solution. For example, an architecture for cloud brokering given in [1] implements dependability properties in an end-to-end way involving different cloud actors and all over cloud service models including SaaS, PaaS and IaaS. However, in such systems with independent IaaS layer and PaaS layer, these two parts have their own message mechanisms and dependent scheduling models, which may cause some problems such as resource state inconsistency[2]. In addition, IaaS cannot perceive the global demand of the development or the task for high-level applications of PaaS layer, so it cannot make optimal scheduling operations.

This work was supported in part by Sichuan Provincial Public Security Bureau of China under Grant No. 2015TD0002, Unicom Cloud Data Co., Ltd of China under Grant No. 2013JQ0005, and Science and Technology Department of Sichuan Province under Grant no. 2017HH0075.

We call this as an IaaS and PaaS isolation problem (IPI problem for abbreviation). Moreover, there are usually massive heterogeneous resources in cloud computing environment. Currently, the unified management of heterogeneous resources (and operating systems) is not well supported in existing cloud operating systems.

IaaS and PaaS are becoming integrated [3]. In this context, aiming at solving the IPI problem and providing the unified management for heterogeneous resources, a new six-layered cloud operating system architecture is proposed in this paper, which is based on the theory of operating system. According to the architecture, a new unified Hua-Cloud Computing System (HCOS) is presented and described.

The remaining parts of this paper are organized as follows. Section 2 describes the architecture model, and the design of HCOS, Section 3 discusses the performance comparison and analysis of HCOS and a few existing cloud operating systems. The related work is discussed in Section 4 and the summary of our research work is given in Section 5.

2 Design and Implementation of HCOS

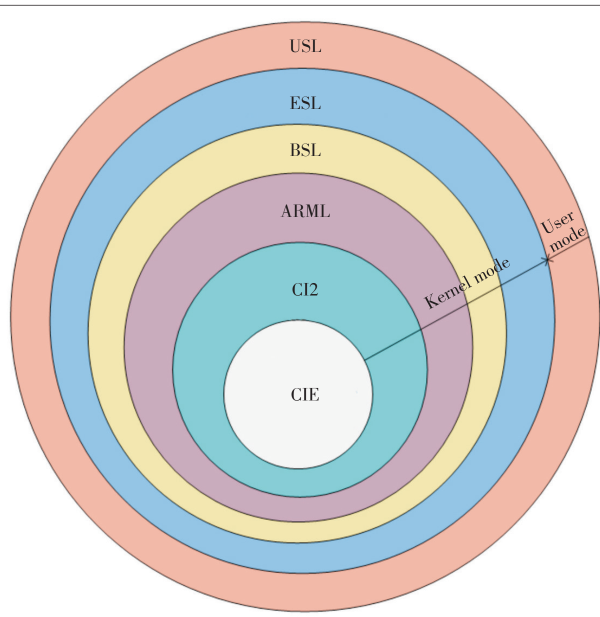
2.1 A Six-Layered Architecture Model of COS

According to the requirements of industrial application and the limitations of existing COS, we present a new unified cloud operating system architecture model referring to the theory of traditional operating system (**Fig. 1**).

As can be seen from Fig. 1, this cloud operating system from the inside to the outside has a total of six layers, and is divided into the kernel mode (from layer 1 to layer 5) and the user mode (layer 6). The working mechanism of this six-layer architecture is similar to the operating system (OS) of personal computer. It has distinctive features and advantages compared with the existing COS architecture. A cloud operating system designed and implemented in this six-layered architecture model can provide both IaaS and PaaS abilities in an integrated way.

The six layers are as follows.

1) Cloud Infrastructure Environment (CIE). It is the first layer and in the most central part within the six-layered model, which indicates the basic environment of cloud computing. It corresponds to the basis hardware of legacy OS. However, it does not belong to the cloud operating system itself. CIE is just used to define the raw infrastructure resource managed by the cloud operating system.
2) Common Infrastructure Interface Layer (CI2). The second layer is CI2, which corresponds to the driver layer of legacy OS. It provides drivers for resources of the infrastructure environment.
3) Abstract Resource Management Layer (ARML). The third layer is ARML, corresponding to the hardware abstraction layer of traditional OS. It achieves an abstract management of all resources defined in the first layer.
4) Basic System Layer (BSL). The fourth layer named BSL is the kernel of COS, corresponding to the logical resource layer (also known as the "kernel") of traditional OS. It supports applications of upper layers directly, and consists of OS installed computing systems, file systems and database systems (with prepared storage devices). Applications are running over this basic layer, similar to applications running over logic resource layer of traditional OS.
5) Enterprise System Layer (ESL). The fifth layer is ESL, which is also the function layer of cloud operating system, corresponding to the system call layer of traditional OS. The main function of this layer is providing business functions. By calling these functions, cloud applications can combine with basic system and then form complete business systems. The ESL also schedules business system in accordance with application requirements. Moreover, in order to adapt to the development trend of big data, it can provide special integrated data management and processing abilities.
6) User Service Layer (USL). The sixth layer is USL, corresponding to the library function and human-computer interaction layer of traditional OS. The main function of this layer is to provide a series of service interfaces, so that users can use cloud operating system conveniently. Through this layer, cloud operating system can be exposed the same abilities as traditional IaaS or PaaS platform. Obviously, cloud operating system can be used as an IaaS or a PaaS platform.



ARML: abstract resource management layer
BSL: basic system layer
CI2: common infrastructure interface layer
CIE: cloud infrastructure environment
ESL: enterprise system layer
USL: user service layer

▲**Figure 1. Six-layered COS architecture model.**

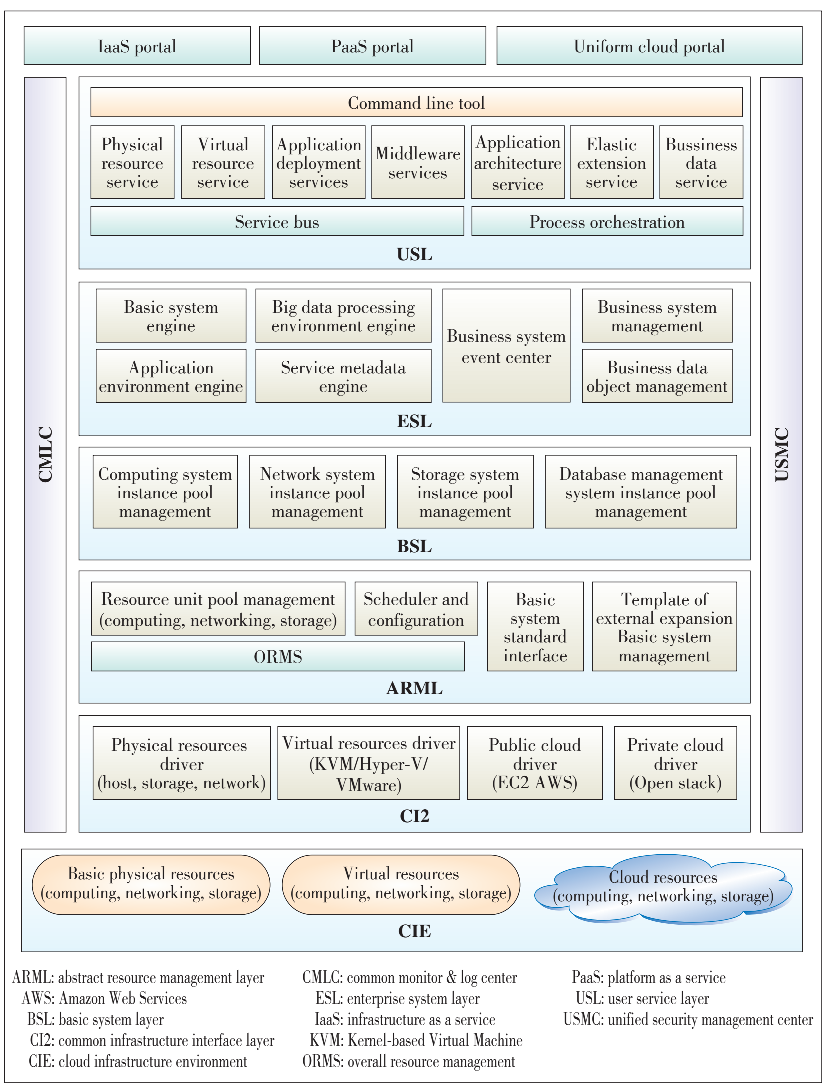
2.2 HCOS—A Implementation of Six-Layered Model

HCOS was designed and implemented according to the six-layered cloud operating system model. Its overall system architecture is shown in **Fig. 2**.

The six layers of HCOS are also CIE, CI2, ARML, BSL, ESL and USL. The basic resources of HCOS could come from public clouds, private clouds or hybrid clouds. ARML takes resources as standard computing, storage, networking, and software templates (including operating systems, database systems, etc.). BSL manages all the instances of the resources coming from ARML. ESL is composed of a number of basic system instances on demand. And USL provides a variety of business systems, resources and capabilities to the user as services. In addition, HCOS also includes Common Monitoring Logging Management (CML) and Unified Security Centre (USC). Above HCOS, we can provide different cloud services through corresponding portals, such IaaS portal, PaaS portal, and uniform cloud portal. The overall architecture of HCOS will be described in detail.

1) CIE

In HCOS, CIE supports heterogeneous infrastructure environment, including common physical infrastructure (computing, networking and storage devices), virtualized infrastructure (virtualized computing, networking and storage devices) and other cloud infrastructure platform. HCOS can support a variety of mainstream virtualization systems such as the Kernel-based Virtual Machine (KVM), Microsoft Hyper-V and VMware ESXi. At the same time, it also supports physical and virtual resources provided by mainstream public cloud platforms such as Amazon Web Services (AWS), or private cloud platforms such as OpenStack. Furthermore, HCOS implements a comprehensive support for hybrid IT architecture by combining internal and external resource services, based on a combination of internal and public clouds.



▲**Figure 2. Detailed system architecture of HCOS.**

2) CI2

As mentioned above, hybrid IT structure is supported in HCOS, so CI2 integrates a variety of different control interfaces, including the driver interfaces of physical resources (host, network, and storage), virtual resources (from different virtualization systems) and the resources of multiple cloud platforms. In this layer, all driver interfaces are described as a general resource object format defined by the ARML, so as to achieve the purpose of uniform resource management.

3) ARML

In HCOS, ARML is used to manage and dispatch all resources. The basic facilities in ARML include compute, network and storage resources. The computing unit, the network unit, and the storage unit are defined in this layer. The core object of a computing unit includes the CPU, memory, disk, network card and other components of a host. The core object of a network unit includes switch, router, and IP, and additional components such as load balancing, firewall, etc. The core object of a memory cell includes disk volumes, file systems and block devices. In addition to the management of hardware infrastructure resources, the management of basic software resources is very important.

4) BSL

BSL is the core of HCOS, also called the logic layer. It is mainly used to provide resource instances based on all software resources and collaborative infrastructure resources. All layers under BSL just manage the basic resources, which are not directly available to the cloud application. So all the software and hardware resources are combined in this layer to become the system level resource services to support the operation of cloud applications. Main objects managed in this layer include computing system, network system, storage system and database management system.

5) ESL

In HCOS, ESL works as the kernel layer. It is used to implement practical supports for HCOS applications. The way is to build an application system which can run business applications, and to coordinate the resource allocation for applications in order to achieve the best resource utilization. ESL provides standard application program interfaces (APIs), so that USL can call all functions of this layer.

The functions of ESL can be divided into three kinds: the application deployment, the operation and management of cloud applications, and the management of data. All messages from the three types of functions are processed in a business system event center. The event center is the message bus of HCOS.

6) USL

In HCOS, USL can invoke three kinds of services directly. The first kind is basic system services, such as physical hosts, virtual hosts, virtual networks, object storage, and elastic load balancing service. The second kind of services are on top of the basic system, including programming environment and running environment, such as database service, middleware, application deployment kit, and elastically stretchable application architecture. The third kind is big data processing services and business data services. This is especially for big data applications.

USL has a process orchestration module, which can organize the order of multiple services to realize user specified workflow. All services are registered on the HCOS service bus. The service bus receives these registrations from the APIs invocated in the corresponding service layer. Based on the abilities of the service bus and process orchestration, various services can be combined to form complete business applications. This approach provides a flexible extension of human-computer interaction. Users can redefine the business model of COS according to their actual demands.

In addition, USL includes a command-line tool which is similar to the shell command in a traditional OS. It is also a basic and important human-computer interaction tool, which provides a means of interacting with HCOS where the user (or client) issues commands to the system in the form of successive lines of text (command lines). Users can call all functional APIs of HCOS kernel layer through entering Python commands into the command-line tool. Moreover, HCOS allows users to call functional APIs with other programming languages by building other forms of command-line tools or graphical portals.

7) Common Monitor & Log Center (CMLC)

The functions of CMLC include:

- Log management: providing the monitoring and log management of all components in HCOS
- Physical environment monitoring: providing the monitoring and log management of physical environment
- Virtual environment monitoring: providing the monitoring and log management of virtual environment
- Basic system monitoring: providing the monitoring and log management of various basic systems
- Business system monitoring: providing the monitoring and log management of all instances of business systems
- Service monitoring: providing the monitoring and log management of running and calling of all services.

8) Unified Security Management Center (USMC)

The USMC is the function enhancement of HCOS from security perspective, mainly including user tenant management, role rights management, identity management, red and white list management, security equipment extension, virtualization, security and logs audit, etc. The red and white list management aims at making some constraints on resource access for certain tenants and users. The security equipment extension function supports effective integration of traditional security devices and systems into the basic system layer, such as firewalls, virus protection, intrusion detection, encryption systems and other external systems. Therefore, it can provide comprehensive security protection for business system. Virtualization security includes new security methods achieved with virtualization technology, and new security protections against virtualization security risks. It mainly refers to the security enhancement method implemented in the virtualization layer. The unified security management mechanism integrates a set of security policies adapted to user scenarios to meet different requirements.

2.3 Key Features

Two key features of HCOS are summarized as follows.

1) Unified messaging mechanism

Current IaaS and PaaS platforms are isolated in resource management, leading to a weak performance caused by different messaging mechanisms. We use a new unified messaging mechanism and an adaptive message synchronization to solve those problems. In this way, HCOS realizes efficient and fast synchronization of all resource status.

Specifically, in HCOS, BSL manages all resources and ESL is responsible for business system management. The collaboration between these two components is implemented through the unified messaging mechanism. All the operations from users within HCOS are sent to ESL by USL. Based on this, the resources used by various system instances are notified to the unified message bus when they are instantiated and managed by ARML. At the same time, the unified controller on BSL can be used to collect the information of each system from the message bus through the unified communication mechanism, and complete the control of system. Finally, using the message broker within each system, information is continuously collected to insure the state consistency of the security and reliability of all instances.

Compared to the structure of existing IaaS and PaaS, the whole system of HCOS is coupled by a unified message mechanism. ARML, BSL and ESL work together to achieve the unified management of resources, business system and basic system instances. As soon as a system instance states changes, each layer's components can automatically adjust to ensure the consistency of business system. The new architecture and message mechanism of HCOS eliminate the boundary of traditional IaaS and PaaS systems, solving the problem that current IaaS and PaaS systems are not consistent in state management.

2) Unified scheduling mechanism

The computing, storage and other resources of current cloud platforms are scheduled independently, which affects the overall scheduling based on the characteristics of applications and leads to low efficiency of resource usage. Moreover, the global optimization cannot be achieved due to the separation of resource adjustment and application demand.

HCOS provides a set of system calls to applications in the business system layer, based on which the application system can define and use resources in the cloud environment flexibly. For the process of application construction, first of all, BSL specifies the resource requirements and the dynamic scheduling strategy of application system in a formal description way. An automated application system construction process is then realized combined with the business characteristics and scheduling strategy. The running process of application system adjusts the resource allocation of BSL according to the operating conditions of application in ESL, so as to achieve the purpose of dynamic optimization of application system resources. For heterogeneous resources, our system has an adapted scheduling strategy.

In addition to run-time scheduling, HCOS also supports presetting a series of behavior patterns or learning new behavior patterns for business systems in running time, and then schedules the resource according to the behavior patterns. The management of behavior patterns reflects the ability of our intelligent mode management system. Usually there are more than one business systems in HCOS, so the scheduling decision must rely on the state of all business systems. If there is no resource competition for two business systems, the policy of as little as possible should be used to ensure the normal operation of these two business systems. Resource requirements of multiple business systems should be considered while scheduling are mainly reflected in the intelligent behavior management system. If users can set the default behavior pattern of the business system, at the time of system deployment, several engines can be triggered when the schedulers are dispatching tasks.

The innovation of unified scheduling mechanism is realized with multi-objective optimization theory, and the intelligent perception approach to user policy, business characteristics and heterogeneous resources features. It breaks through the traditional independent scheduling of resources and services.

3 Performance Evaluation

3.1 Performance Comparison

Table 1 compares HCOS with VMware's vCloud [4] and Cloud Foundry [5], and OpenStack [6], regarding the fusion of IaaS and PaaS, the heterogeneousness (heterogeneous cloud platforms and resources management) and the unified scheduling mechanism. These three aspects of competence are incomplete with VMware. OpenStack is an IaaS level solution, focusing on platform virtualization and cloud resources management, including virtualization engine, cloud management components, virtual functions and resource pool management, and cloud service components. As a result, it has only some heterogeneous resource management capabilities. Comparing with them, HCOS focuses on the integration of IaaS and PaaS in the effective management of massive hybrid and heterogeneous resources.

▼Table 1. Comparison of a few COSs

Features	VMware	OpenStack	HCOS
Fusion of IaaS & PaaS	No	No	Yes
Heterogeneousness	No	Partial	Yes
Unified Scheduling Mechanism	No	No	Yes

HCOS:Hua-Cloud Computing System IaaS: Infrastructure as a Service PaaS: Platform as a Service

3.2 Typical Applications of HCOS

3.2.1 Public Security Cloud Based on HCOS

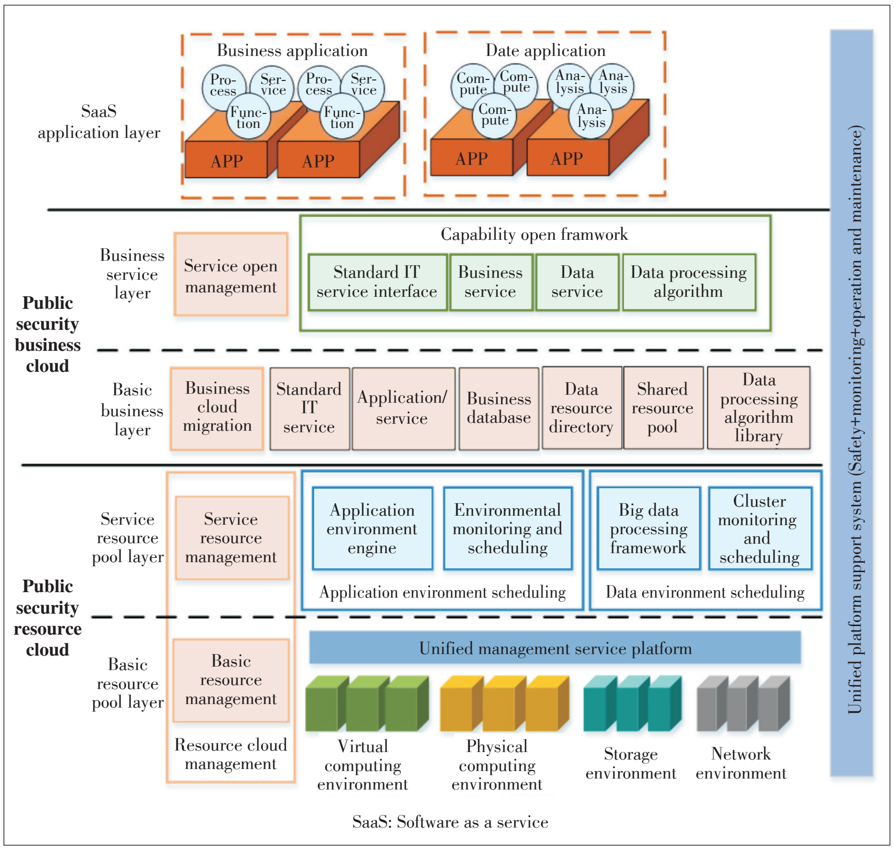
Public Security Cloud based on HCOS is a provincial public security information system, which is consisted in multiple data centers. Public Security Cloud has an overall structure as shown in **Fig. 3**.

The whole Public Security Cloud is divided into three levels. The first level is the public security resource cloud platform, which can provide basic resources, service support, big data processing and other types of services. The second level is the public security business cloud platform, which mainly includes application transforming and data processing services. These two parts are fully supported by HCOS. The kernel and fundamental technology of the second level is integrated with big data management. The third level is a dedicated SaaS layer focusing on public security field, constructed by new generation of public security applications. This Public Security Cloud has been put into use since May 2014.

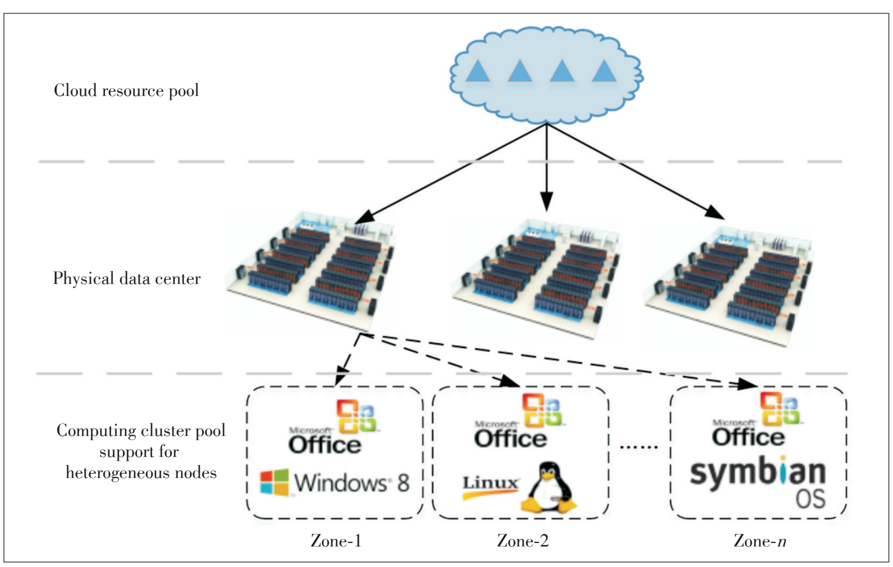
3.2.2 China Unicom Cloud Based on HCOS

As shown in **Fig. 4**, China Unicom Cloud system is a large scale and integrated business cloud platform. It supports heterogeneous nodes to constitute resource pool clusters, providing intelligent resource scheduling, dynamic adaptation, and comprehensive and accurate reforming capabilities for large-scale resource management.

Using a set of unified management interfaces and interactive portals, China Unicom Cloud can realize the management of cloud host and cloud storage resources for design, creation, test, verification, maintenance and recovery in all the life cy-



▲Figure 3. Overall structure of Public Security Cloud by HCOS.



▲ Figure 4. General structure of China Unicom Cloud Based on HCOS.

cle. Snapshot and template methods are adopted, enabling rapid and efficient management.

4 Related Work

In recent years, the research of cloud computing has made big progress. Google has issued GFS [7], BigTable [8] and MapReduce [9]. Amazon has provided EC2 [10] and S3 [11]. Microsoft has raised Windows Azure [12].Some other companies and research institutions also have had their own cloud computing technologies and products. However, the concept and the ability requirement of the cloud computing system were not established at the beginning. Currently, some research focuses on the cloud storage and cloud virtualization. With the emerging technologies mainly concentrating in the performance of the cloud, there were also a few concerns about cloud operating systems [12], [13]. Table 1 provides a comparative study on a few typical COSs. The problems such as the fusion of IaaS and PaaS, unified management for heterogeneous resources, and unified scheduling mechanism have not been well studied.

Amazon [6] aims at providing services at the IaaS layer. Gagana et al. [2] discuss the function provided by the existing PaaS platform with an emphasis on the efficiency of application development. The advantages of the PaaS platform are analyzed by Lawton et al. [14], especially on how PaaS increases the production efficiency of enterprises. Serrano et al. [15] analyze the current state of cloud computing to provide users with help on how to select a suitable infrastructure. Steve et al. [16] present the OpenStack platform to support the heterogeneous framework.

There are quite a few cloud operating systems such as OpenStack [6], VMware vCloud [4], and Cloud Foundry [5]. OpenStack just provides IaaS ability. It can realize effective management of virtualized resources, but does not provide application and service middleware management. VMware vCloud and Cloud Foundry are two independent COS products. The former focuses on the virtualization of hardware resource management, while the latter is a typical PaaS platform. These COSs are closely related to our work and we considered their advantages for the design of our new architecture.

5 Conclusions

This paper presents a unified six-layered cloud operating system referring to the operating system theory of traditional PC. HCOS is designed and implemented based on this new

COS architecture model. In view of the abilities and shortcomings of a few existing COSs, HCOS focuses on the integration of IaaS and PaaS, the heterogeneous platform management and the unified scheduling mechanism. It achieves resource state consistency and fast response based on unified messaging and scheduling mechanism. Users can run any service needed on their devices without concerning themselves with the underlying technologies, and can obtain timely response. HCOS provides a multi-level management structure together with a multi-point structure for heterogeneous resources.

Our future research will focus on the following issues:

1) Improving interface standards of our unified messaging mechanism and strengthening the timeliness of resource scheduling. This work can further help the fusion of IaaS and PaaS. We are also developing parallel scheduling for HCOS to improve the efficiency of resource allocation.
2) Improving the efficiency and intelligent capabilities of big data processing. Current HCOS provides a framework with the unified business system data object that may be distributed in different business applications. We are considering solutions to further improving the efficiency and intelligent processing capabilities of big data with data communication security across different areas.
3) Extending HCOS to more application areas, such as digital home applications. Currently we are evaluating HCOS in the public security cloud and heterogeneous resource cloud with PCs and Tablet computers.

Acknowledgment

The authors would like to acknowledge the helpful comments of anonymous reviews, guest editors and the participants of HCOS projects.

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Manuscript received: 2017-05-10

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