Cloud Operating System for Industrial Application

Gang Xiong[1, 2], Tongkai Ji[1], Xipeng Zhang[2], Fenghua Zhu[2], Wenjing Liu[1]
[1] Cloud Computing Center, Chinese Academy of Sciences, Guangdong, 523808, China
[2] The State Key Laboratory of Management and Control for Complex Systems, Institute of Automation, Chinese Academy of Sciences, Beijing, 100190, China
E-mail: gang.xiong@ia.ac.cn

***Abstract*—With the rapid development of latest information technology, it is inevitable to apply IoT (Internet of Things), cloud computing and big data into the industrial fields of national key sectors including transportation, electricity, metallurgy, petroleum, chemical, manufacturing, military and so on. Wireless sensor network, industrial Internet, embedded system, software for industrial control and management, and smart terminal are gradually introduced into the industrial systems, which would make the past relatively closed industrial systems more open and intelligent, and contribute to the coming forth industrial revolution. In this paper, the authors mainly discuss issues about cloud Operating System (OS) for industrial application, including cloud computing and cloud operating system introduction, current status analysis of cloud OS and the transformation trend to industrial 4.0. Then, we independently design the main content of this cloud OS, and its application prospect and expected result are given. The study provides theoretical guidance and practical challenge for the development of cloud OS oriented to industrial area.**

Keywords*—*Internet of Things; Big data; Cloud Computing; Cloud Operating System; Industrial 4.0; G-Cloud OS for Industrial Application;

I. INTRODUCTION

With the rapid development of latest information technologies, a new development wave is led by IoT (Internet of Things), cloud computing and big data which are the hottest new generation technologies after parallel computing, distributed computing and grid computing. Cloud computing is a mixed and integrated result of the novel concepts including virtualization, utility computing, IaaS (Infrastructure as a Service), PaaS (Platform as a Service) and SaaS (Software as a Service). Cloud computing is a dynamical and scalable computing mode where all resources including network, servers, storage, application, and computing are virtualized and provided as a service over the Internet. For the following reasons, cloud computing has such advantages as strong compatibility, low cost and high efficiency, so it could bring more economic value and benefits for enterprises and users[1]-[2]:

1) Cloud computing can be formed by those existing cheap computing nodes due to its special fault tolerance measurements;
2) The cloud computing resources are centrally managed and maintained, so enterprises and users just pay for the customized services, saving unnecessary procurement and maintenance cost of expensive computing infrastructure;
3) Cloud service provider can develop and provide specialized application functions for different kinds of users. The versatility of cloud computing makes its resources more valuable and useful than traditional system.

As an adaptable extension of traditional stand-alone OS, cloud OS must be developed independently to assure the cloud computing security and its large-scale application. Compared with traditional OS, cloud OS provides a complete set of services compatible with most types of infrastructure including network, hardware, software, terminals, and application.

Based on complete and standard cloud OS, a variety of better application services can be provided rapidly by building and managing the whole cloud computing infrastructure. In general, cloud OS includes three main functions:

1) Centrally manage and maintain huge amounts of computing infrastructure, such as servers and storage, by integrating hardware resources of all connected data centers into one single virtual cloud server.
2) Provide unified and standard function, service and interface for different applications. Every user selects and pays for the cloud-based application services in needed.
3) Dynamically manage the massive computing tasks, application deployment, and different resources migration.

Cloud OS is the core of managing all kinds of resources, just like the brain of the whole cloud infrastructure. The kernel technology of cloud OS should be researched and developed independently to ensure the security of the whole cloud infrastructure.

In this paper, the authors mainly discuss and design cloud OS for industrial application. Cloud computing and cloud OS is introduced in section I. Current status of cloud OS is analyzed in section II along with detail information about the structure and function of domestic G-Cloud OS. Section III deals with the transformation trend to Industrial 4.0 and its main challenges. The main content of cloud OS for industrial application is independently designed in section IV, and its application prospects and expected results are given out in section V. Finally, conclusions are drawn out in section VI.

978-1-4673-8480-3/15/$31.00 ©2015 IEEE

II. CURRENT STATUS ANALYSIS OF CLOUD OPERATING SYSTEM

Cloud computing is the developing direction of information technology, which has become a common view among most of governments and industries all around world. From perspective of applications, users can access to cloud-based resources over the Internet, select on-demand services and then pay just for his/her consumption. Meanwhile, from the point of service, cloud computing could provide compatible environment and configurable services by integrating all kinds of heterogeneous software, hardware and the dynamic flow of resources. In summary, these are the two basic functions of cloud operating system.

Companies such as Google, IBM, Microsoft, Oracle, SAP and Amazon have developed their own cloud OS [3]-[6]. For example, Google has developed its cloud OS named as Chrome OS and the intelligent terminal OS named Android. Until 2014, its open Android OS has occupied more than 80% of the world's mobile phone OS market share. The giant software companies, like SAP and Oracle, mainly provide enterprise cloud solutions. For example, Oracle Database Cloud Service provides cloud service on the database layer, while Oracle Java Cloud Service provides cloud service on the application layer. VMware and vSphere are open cloud OSs, which can be purchased from the market for application development.

So far, the most of cloud computing applications are built on the cloud OS, which are developed and managed by few companies of developed countries, and this situation is unfavorable to IT infrastructure security of other countries. Thus, some governments and enterprises begin to pay more attention to the research and development of their own cloud OS. At present, we find a list of independent cloud OS, including the GalaX OS developed by HuaWei and Intel cooperatively, Fusion Sphere cloud OS of HuaWei, CoCloud OS of ZTE, TransOS developed by Yaoxue Zhang's group from Tsinghua University, which is based on transparent computing, and integrates the existing Linux, Windows, Unix and Symbian [7]. Chinese universities and companies design and develop a series of Kylin operating systems, like special cloud OS dedicated for TianHe and Galaxy high-performance servers, Neo Kylin cloud OS for universal server and user terminal which was jointly developed upon Linux kernel with CS2C[8]. In 2013, "TianHe 2" was built up by Guangzhou supercomputing center, its Kylin cloud OS uses SLURM（Simple Linux Utility for Resource Management), and Ubuntu OpenStack, which are running on thousand of computing nodes. Its floating point computing speed reaches 33.86 thousand trillion times per second, so it becomes the fastest machine and champion during previous global competitions more than 5 times.

In addition, Inspur Group launched an independent cloud OS, which is an open architecture, modular, standardized resource management platform of cloud data center. In PC era, OS was dominated by Microsoft, and OS of mobile terminal was dominated by Apple and Google. In November 2014, many experts from "Chinese Intelligent Terminal Operating System Industry Alliance" called for independent research and develop cloud OS for intelligent terminal application, to assure information security of domestic OS and its industrial application.

Cloud Computing Center, Chinese Academy of Sciences has designed and developed an independent cloud OS named G-Cloud jointly with its partners, which can support the virtualization and unified management of large-scale computing resources, storage resources, and network resources. With the help of G-Cloud, any private cloud, public cloud or the mixed cloud can be built upon the existing IT Infrastructure, which is extensible, controllable, and reliable. G-cloud adapts completely independent and controllable core technology and large-scale intensive resource management, and provides safe and reliable cloud computing platform. As depicted in Fig. 1, the framework of G-cloud contains the following layers [9]:

1) Hardware layer (Adaptation layer of hardware resources): The open system architecture of G-Cloud could manage different kinds of hardware infrastructure including traditional hardware, servers, storage, and network devices like switch and firewall, and safety protection devices like intrusion detection system, intrusion prevention system.

2) OS Layer (Adaptation layer of operating system): G-Cloud could realize information interaction among a variety of operating systems from universal Windows, Linux, Unix to generalized OS-hypervisor including Xen, KVM, vSphere, HyperV and specialized OS for hardware devices, and integrate resources under their operating systems.

3) Communication Adapter Layer: This layer promotes resources to integrate into G-Cloud, provides communication ability between components and a unified interface for heterogeneous language platforms, and supports plug-and-play of hardware resources;

4) Resource Driven Layer: Different manufacturers normally provide different interface for resource management. The layer aims to provide a unified operation interface for resources management of different manufacturers;

5) Interface Layer: G-cloud provides appropriate and standard interfaces for different type of users and applications.

6) Cloud Middleware Layer: It provides a unified logic interface for application developers.

7) Application Driven Layer: It provides an application developing interfaces for application developers of industry business;

8) Application Layer: It is designed to provide cloud-based specific applications for different industries.

Based on perfect system architecture and delicate layer design, G-Cloud own two advantages: one is management service, and the other is security protection. Management system will realize the management functions of application, application driver, resource, task, S&C (Supervision and Control), resource driver, communication, OS and hardware. Security system manages App security, data security, communication

security and identity security. G-Cloud can realize scalable, reliable and controllable private cloud, public could and hybrid cloud on the basis of existing IT infrastructure, and can increase the utilization rate of traditional server from 10% to 70%, together with the reliability of cloud data as high as 99.99%. G-Cloud was awarded as an outstanding cloud computing solution for its security and controllability by Chinese MIIT (Ministry of Industry and Information Technology) in August 2011. Then in July 2014, G-Cloud became China's first cloud OS to pass the EAL3 evaluation and acquired the EAL3 level certificate signed by Chinese National Information Security Evaluation Center.

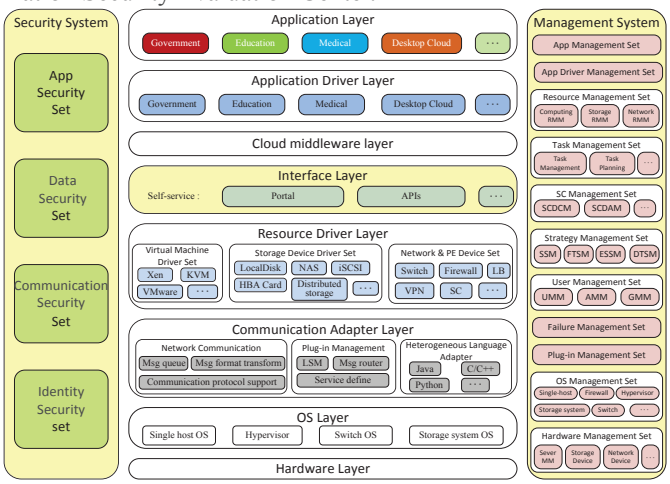

Figure. 1 G-Cloud cloud operating system (source: www.g-cloud.com.cn)

With the development of information technologies, the latest industrial IoT and cloud computing will be widely introduced into those national key industries, like transportation, electricity, metallurgy, petroleum, chemical, manufacturing, military and so on. Take industrial control field as example, most of international famous companies like Siemens, ABB, Emerson, Honeywell, Rockwell, Schneider, Yokogawa, General Electric, Mitsubishi Electric and so on, are making their attempts on developing industrial cloud[10]-[12]. ABB has moved its SCADA to GlobaLogix for providing the high reliability and redundancy of cloud computing infrastructure, its 2048 Bit key is in line with the U.S. Department of defense standards, its infrastructure is in line with the U.S. Communications Industry Association (TIA) and the National Institute of standards (ANSI) requirements for critical computing system. MAXPRO Cloud developed by Honeywell realized the monitoring system for all-weather management over Internet. Based on Windows Azure cloud computing platform, Siemens in cooperation with Microsoft developed a product lifecycle management system oriented to all industrial automation equipments. We are not ready for the coming industrial automation revolution inspired by cloud computing. Since 2009, with the 973/863 funding support from MOST, academician scientists Bohu Li of CASIC (China Aerospace Science & Industry Corp.) and his team began to promote the cloud technologies and systems for discrete manufacturing industry that possibly bring a new business form "cloud manufacturing", which is an advanced manufacturing mode created by the combination of cloud computing and IoT (Internet of Things) in keeping with the demand of manufacturing industries. But this new form is still absence of support from own IaaS (Infrastructure as a Service), cloud OS, and network security solution, all of which should be researched and developed independently.

III. TRANSFORMATION TREND TO INDUSTRIAL 4.0

The concept of "Industrial 4.0" was proposed at the Hannover Fair by the German federal actuarial-oriented and the federal ministry of economic affairs and technology in 2013. The academia and industry in German consider the fourth industrial revolution with intelligent manufacturing as a dominant role or a revolutionary method of future manufacturing industry. The "Industrial 4.0" strategy aims to lead the manufacturing transformation from tradition to intelligence [13]-[14]. Industry 4.0 depicts an ideal vision of the future manufacturing industry. After the industrial revolutions of steam engine, mass production, electronics & information technology, manufacturing will enter in a new era, where all manufacturing things are connected by wire/wireless networks, all the production data of manufacturing CPS (Cyber-Physical System) will be collected, stored and used. The new manufacturing form aims at promoting the intelligent level of industry, by building up an adaptive, efficient and smart plant, and integrating customers and business partners into the value chain processes simultaneously.

"Industry 4.0" is not only an extension of traditional IT into the industry field, but also full of connection between people and things, things and things. A stable "Industry 4.0" eco-system needs more assurances about a stronger network and data security protection, a stronger support for long-distance data storage, data backup, data processing, data analysis and visualization. In the meanwhile, it will realize digital management of the entire production chain, achieve a state that all the machines are interconnected, and the entire production process conditions will be tracked automatically [15]-[16].

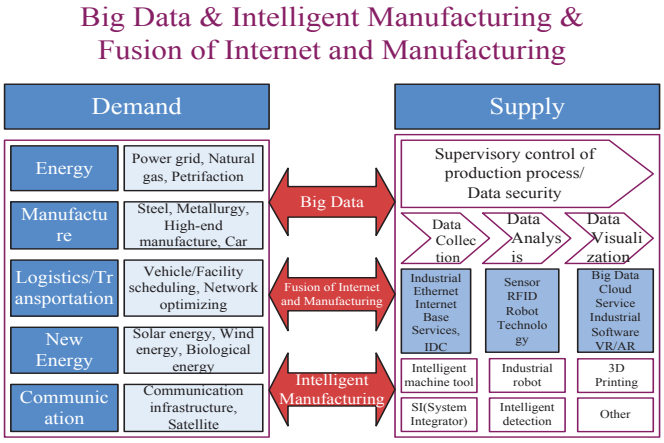

Figure. 2 Big data & intelligent manufacturing & integration of Internet and manufacturing (source: eguan.cn)

With the development of industrial IoT, more and more sensor nodes will be deployed to collect huge amounts of manufacturing data, and meanwhile an increasing number of execution nodes are set up in industrial field to accomplish more accurate M&C (Management and Control) function. For the reason that the transmission of industrial signals, including control signal and sensing signal, is layered and progressive, industrial system emphasizes instantaneity, accuracy and reliability of information transmission. The character of industrial system and huge quantity of manufacturing data make it impossible to adopt traditional information processing methods to solve the problem. The industrial cloud platform offers a new solution to store, analyze, process and utilize the data generated along with intelligent manufacturing processes. Therefore, in order to ensure information security of "Industry 4.0", we need pay more attention for industrial information protection, where cloud OS for industrial application is one fundamental part.

During the transition process to "Industry 4.0", the main problems and challenges include the following aspects:

1) Relative lake of basic theory research and weak capacity for independent research and development in our country: technical system is not complete, and the whole design capacity on independent R&D of manufacturing industry is insufficient and lack of original innovation;

2) Lack of all kinds of complex product design, intelligent high-end software products like 3D CAD (Computer Aided Design): hardware is invested much more than software in China;

3) Lack of accumulation in the field of related core patent technology: We have not yet grasped the core system design and manufacturing technology of many important equipments and manufacturing processes. And many key technologies and core infrastructure components are still dependent on imports from aboard countries;

4) Weak safeguard hierarchy for information transmission and incomplete information authorization management: information security problems of industrial control systems are critical, mainly includes the function security like enterprise information protection, and data security like privacy protection, etc.

Cloud OS for industrial application is an important part of industrial network, industrial control system and their information security, thus independent R&D of cloud OS for industrial application become a crucial part for our country's transformation to "Industry 4.0", and meanwhile a significant reflection on promoting our country's innovation ability.

IV. MAIN CONTENTS OF CLOUD OS FOR INDUSTRIAL APPLICATION

Compared with the existing industrial system hierarchy, in the process of realizing industrial cloud, we need to accordingly satisfy the function and performance requirements of business management cloud, plant management cloud, production control cloud and industrial cloud terminal such as mobile phones, car-mounted terminals and so on. Take business management cloud operating system for example, it is the comprehensive management system for background data center of enterprise cloud that bases on hardware resources including servers, storage, network, software resources including single operating system, middleware and database, by which the masses of the basic hardware and software resources are managed. Enterprise cloud OS has the modules of large-scale hardware and software management, virtual computing management, distributed file system management, business/resource scheduling management, safety control management and so on. Hardware resources in a data center are logically integrated into a single server by managing and driving huge amounts of network service, storage and other basic hardware. The enterprise cloud OS provides a unified and standard interface for enterprise cloud applications and manages massive computing tasks and resource allocation.

The main function of enterprise cloud OS contains computing resource management, storage resource management, network resource management, key pair management, security group management, mirror image management, supervisory control management, user management, system configuration management. And its main components includes front proxy, cloud controller, cluster controller, storage controller, master node controller, standby node controller, certificate authority (CA), controller of supervisory control and so on. Computing resources management mainly has two kinds of operations, as to virtual machine, it has basic operation of creation, start up, shut up, restart, transfer and rename; as to the operations to internal data of virtual machine, it contains configuration, backup, package, logging in, installing and extension of component. The modules of system management include business units of user management, maintenance of dictionary, virtual machine configuration, operating log, network planning, access to equipment, task planning, management of recycle bin, mapping files and images. The main parameter indexes of enterprise cloud OS are as follows:

1) Efficient virtual computing model mainly reflected in: infrastructure virtualization, on-demand usage and an increase of 30% in resources utilization rate;

2) High availability and reliability of the cloud computing mechanism: unified management of multicenter, migration of virtual machine (second), copy of multi-backups, failure recovery, fault-tolerant (millisecond interruption), etc.;

3) Supporting for dynamic resource scheduling, elastic computing resources. And storage and providing a unified monitor interface for administrator;

4) Flexible compatibility with the original policy: the entire service platform could be fully compatible with the original IT management strategy and keep the strategy of original network management and security management unchanged by which users can select more flexible allocate strategy;

5) Secure connection: To ensure the applied resources of

user are safe; Third-party security solutions, firewall and Internet Protocol Suite (IPS) could be quickly compatible;

6) Reliable service: Both computing resources and storage resources get through all reliability tests, by which the availability of service and resource could be ensured.
7) To realize dynamic migration, fault tolerance of virtual machine, load balancing, failure recovery, etc.

V. APPLICATION PROSPECT AND EXPECTED RESULT OF INDUSTRIAL CLOUD OS

An industrial system contains four parts: its three layer subsystems (enterprise management layer, plant management layer and production control layer) and user. In the process of the development of industrial cloud, cloud OS oriented to industrial control area should not only manage industrial system's three layer subsystems, but also respectively satisfy the requirements of different users. To get rid of our dependent on foreign technology, we must independently research and develop industrial could OS. The requirements of industrial cloud OS faced to industrial system's four parts are as follow:

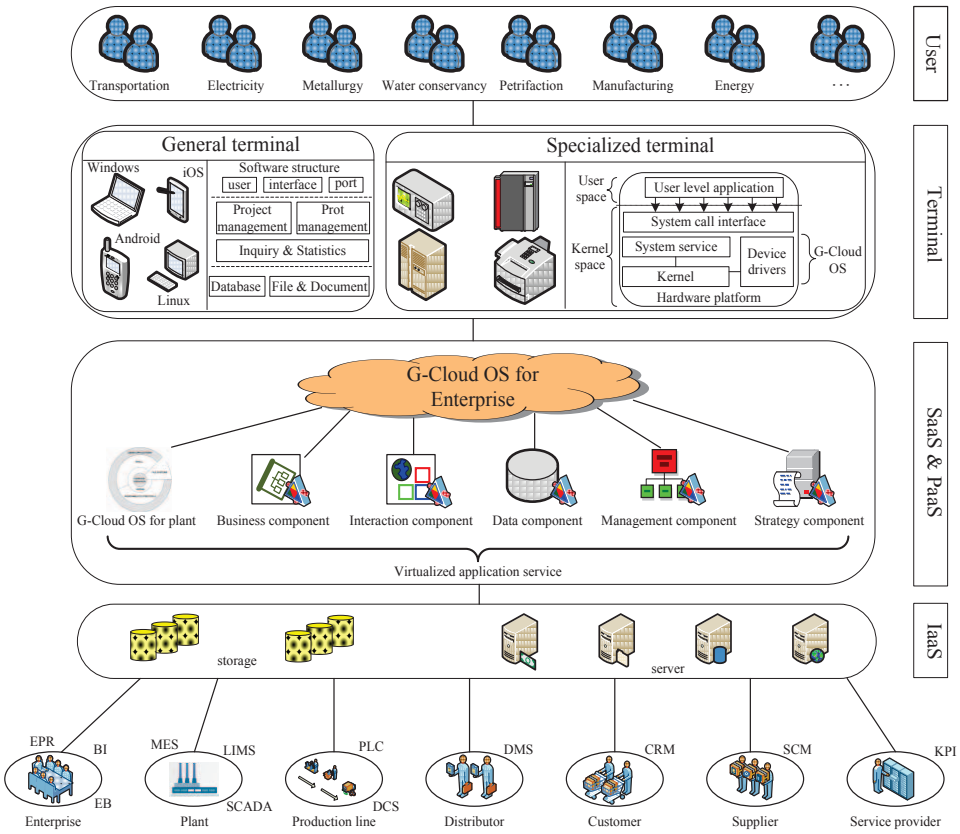

Figure. 3 The architecture and composition of industrial G-Cloud

1) On the basis of G-Cloud, independently-developed cloud OS of our nation, enterprise management cloud OS need to be compatible both with domestic enterprise application systems such as ERP (Enterprise Resource Planning), CAD, SCM (Supply Chain Management), ERM (Enterprise Resource Management) etc. and basic domestic hardware and software resources including industrial cloud serves, industrial network, and industrial middleware.
2) Plant management cloud OS must be independently designed to be compatible with domestic systems such as MES (Manufacturing Execution System), SCADA (Supervisory Control And Data Acquisition), LIMS (Laboratory Information Management System), etc. and satisfy the requirements of security.
3) As to production control management, it also needs to be independently researched and developed to meet the requirements of industrial security and be compatible with domestic industrial control equipments including DCS (Distributed Control System), PLC (Programmable logic controller), and NCS (Numerical Control System).
4) In order to satisfy the strict requirements for instantaneity and reliability of industrial cloud terminal, user terminal OS can be modified and improved on the basic of some existing domestic intelligent operating systems. With the help of kernel security enhancement technology and sensitive data protection technology, domestic mobile terminal OS can break through technology bottleneck in bug fixing, network security, malicious software prevention, indentify confirmation, authorization management, access control, data encryption and protection, and take procession of independent intellectual property rights.

Figure 3 shows the architecture and composition of industrial G-Cloud, which will provide an expected manage-

ment-control integration solution for our nation's industrial enterprises. With the help of domestic enterprise application systems including ERP, CRM (Customer Relationship Management), EB (Electronic Business) and BI (Business Intelligence), enterprise management layer is designed to realize the function of management and optimization of personnel assignment, financial transactions, and supply and marketing [17]. In plant management layer, the solution would helps to manage order information, raw material supply, production planning and employee performance, where customized systems such as MES, LIMS and MII (Manufacturing Integration Intelligence) are needed according to the requirements of different industries and enterprises. As to production control, it is mainly responsible for the cooperative control and optimization of various parameters of industrial field apparatus. User terminal can be divided into two parts: general terminal and specialized terminal. Considering the special requirements and information security of some industries, plants and production lines, we must develop independent hardware resources, terminal OS, application software for specialized terminal. On the basis of foreign terminal OS, information encryption methods and self-application need be used in general terminal to ensure the instantaneity and reliability of information transmission which is crucial to industrial control system.

VI. CONCLUSIONS

The global industry is developing to the orientation of "Industry 4.0" that is more automatic, informational and intelligent. As one of the powerful manufacturing nations in the world, China should occupy an important position in the coming industrial revolution. The primary strategic task of keeping a powerful nation in the field of manufacturing is to improve the national innovation ability constantly and to deepen the fusion between informatization and industrialization. Researching and developing independent industrial cloud OS is one of important tasks, it can assure the network, information, functions and services security on the developing way of "Cloud Manufacturing", and "Industry 4.0".

ACKNOWLEDGMENT

The correspondence author would like to acknowledge support in part from the National Natural Science Foundation of China under Grants 71232006, 61233001, Finnish TEKES's project "SoMa2020: Social Manufacturing" (2015-2017), Chinese Guangdong's S&T project (2014B010118001, 2014A050503004), Chinese Dongguan's S&T project (2013508102018) and Dongguan 's Innovation Talents Project (Gang Xiong).

REFERENCES

[1]. Derrick Kondo, Bahman Javaid, Paul Malecot, Franck Cappello and David P. and Anderson, "Cost benefit analysis of cloud computing in education", *2012 International Conference on Computing, Communication and Applications (ICCCA)*, pp. 1-6, 2012.

[2]. Rajkumar Buyya, Rajiv Ranjan and Rodrigo N. Calheiros, "Modeling and simulation of scalable Cloud computing environments and the CloudSim toolkit: Challenges and opportunities", *2009 International Conference on High Performance Computing & Simulation*, pp. 1-11, 2009.

[3]. Integrated Cloud Application & Platform Service of Oracle. Available: http://www.oracle.com/us/corporate/features/complete-cloud/index.html

[4]. IBM cloud computing is designed for business. Available: http://www.ibm.com/cloud-computing/us/en/

[5]. Microsoft Cloud. Available: http://www.microsoft.com/enterprise/microsoftcloud/Default.aspx

[6]. SAP Cloud Computing. Available: http://www.sap.com/china/pc/tech/cloud.html

[7]. Zhang YaoXue and Zhou YueZhi, "A New Cloud Operating System: Design and Implementation Based on Transparent Computing", *Acta Electronica Sinica*. 2011, vol. 39, pp. 985-990.

[8]. Kylin Operating System. Available: http://baike.baidu.com.

[9]. G-Cloud Independent Security Controllable Cloud Computing Version6.5 Product White Paper. Available: http://www.g-cloud.com.cn

[10]. ABB and GlobaLogix partner to provide SCADAvantage in the cloud for oil and gas companies. Available: http://www.automationworld.com/cloud-computing

[11]. Honeywell Announces Cloud API Program With Home Automation Software Developers. Available: http://www.maxprocloud.eu/

[12]. Siemens Cloud Computing. Available: http://www.siemens.com

[13]. Xiwen Wang, "Industry 4.0: intelligent industry", *Internet of Things Technologies*, 2013, vol. 12, pp. 3-6.

[14]. Xiwen Wang, "A view of future intelligent manufacture on the basis of German industry 4.0 strategy", *China Informatization*, 2014, vol. 15, pp. 7-8.

[15]. Gang Xiong, Xisong Dong, Xiwei Liu and Nyberg Timo R, "Real-time manufacturing integration and intelligence solution", *Case Study in Global Chemical Company*, July, 2012, vol. 8, pp. 1727-1737.

[16]. 2015 industry 4.0 research report. Available: http://www.analysys.cn/

[17]. Xiong Gang, "The development trend and instance analysis of enterprise resource plans", *the Information Work Dynamic of CAS (second periodical)*. pp. 18-32.