Modeling and Simulation of Cloud Computing: A Review

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***Abstract*—Cloud computing provides computing resources as a service over a network. As rapid application of this emerging technology in real world, it becomes more and more important how to evaluate the performance and security problems that cloud computing confronts. Currently, modeling and simulation technology has become a useful and powerful tool in cloud computing research community to deal with these issues. In this paper, to the best of our knowledge, we review the existing results on modeling and simulation of cloud computing. We start from reviewing the basic concepts of cloud computing and its security issues, and subsequently review the existing cloud computing simulators. Furthermore, we indicate that there exist two types of cloud computing simulators, that is, simulators just based on software and simulators based on both software and hardware. Finally, we analyze and compare features of the existing cloud computing simulators.**

Index Terms*—Cloud computing, cloud security, modeling and simulation, cloud simulator.

I. INTRODUCTION

Cloud computing technology is developing quickly in recently years. This emerging computing model enables ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) [22]. With the very attractive features, cloud computing has been widely applied in industry community, businesses, consumers and government organizations, and also obtained huge attention in academy community. Along with the research, development and application of cloud computing, its security and privacy problems also emerge.

Very recently, it becomes more and more important to study and analyze how cloud computing and the applications which are deployed on clouds will perform, whether cloud computing services are secure and privacy-preserving, and which cloud computing service users can choose. As the experimentation in a real environment is expensive, time costly, and not repeatable [8], it is often hard to analyze the performance and security issues on actual cloud environments. Therefore, modeling and simulation technology becomes increasingly popular in the cloud industry and academy. It is well known that modeling and simulation technology is a method which is often used to analyze complex problems in the physical world, most simulation-based experiments consider simplified modeling of cloud computing and application environments [35].

In the literature, some traditional distributed system simulators [5, 13, 20] can't provide the environment that can be directly used by the cloud computing community. Therefore, a lot of works [2, 9, 18, 21, 23, 24, 29, 30, 31, 32, 37] pay much attention on this issue, and simulators [9, 16, 17, 25, 32, 37] designed for cloud computing specially were introduced in the last few years. Briefly, these simulators can be broadly divided into two types: simulators just based on software, simulator based on both software and hardware.

In this paper, we summarize the existing results on modeling and simulation of cloud computing that we can know to the best of our knowledge. Moreover, from three aspects of underlying platform that simulators are based on, developing language that simulators use, software or hardware that designed simulator is, we analyze and compare features of the existing cloud computing simulators. Thanks to the modeling and simulation technology, cloud computing simulator is now flourishing within the research community of evaluating the performance and security of cloud computing.

II. PRELIMINARIES

In the industry and academy, there exist many definitions for cloud computing and is no canonical one. In this section, we review the definition of cloud computing proposed by National Institute of Standards and Technology (NIST). Meanwhile, we review the security issues that cloud computing confronts.

A. Definitions of Cloud Computing

In 2011, NIST [22] defined cloud computing as a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model consists of five essential characteristics that are on-demand self-service, broad network access, resource pooling, rapid elasticity, measured service; three service models that are software as a service (SaaS), platform as a service (PaaS), infrastructure as a service (IaaS); and four deployment models that are private cloud, community cloud, public cloud, hybrid cloud.

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B. *Security Issues of Cloud Coputing*

Security of cloud computing is always an important consideration for users when adopting cloud services. Cloud Security Alliance [12] indicates that cloud computing confronts the following top security threats: 1) abuse and nefarious use of cloud computing; 2) insecure interfaces and APIs; 3) malicious insiders; 4) shared technology issues; 5) data loss or leakage; 6) account or service hijacking; 7) unknown risk profile.

III. Modeling and Simulation of Cloud Computing

In this section, we summarize cloud computing simulators proposed in the literature which are aimed to evaluate the performance and security of cloud computing systems, and describe the main features of these simulators.

A. *CloudSim*

To solve the problem that none of the distributed system simulators before 2009 can be applied in the cloud computing environment, Calheiros et al. [9, 10] and Buyya et al. [6] proposed CloudSim that is a simulation software and enables seamless modeling, simulation, and experimentation of cloud computing and the application services. Moreover, the authors indicated that users can focus on investigating specific system issues through CloudSim, without considering the low level details related to Cloud-based infrastructures and services. The layered CloudSim architecture is shown in Fig.1.

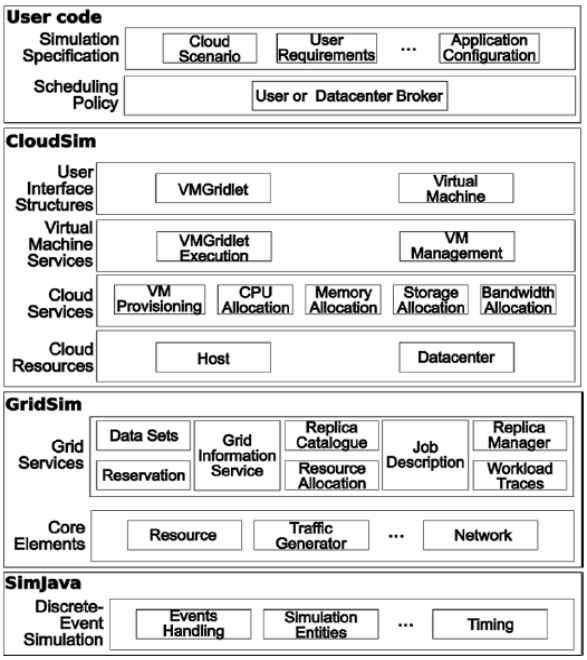

Fig. 1 The layered CloudSim architecture

Later, several works tried to improve CloudSim. In Werner et al.'s work [36], the authors proposed an organization theory model for resource management of the green clouds based on organization models, network management, and distributed computing; and improved CloudSim to validate the green cloud computing approach. Moreover, Belalem et al. [3] focused on reducing and eliminating various failures encountered during the submission of job in the simulator CloudSim.

B. *CloudAnalyst*

In 2009, Wickremasinghe [37, 38] proposed a new simulation tool CloudAnalyst, as shown in Fig.2, which was designed directly based on CloudSim and extends some of the capabilities of CloudSim. This simulator can be applied to study the behavior of large scaled Internet application in cloud environment and separate the simulation experimentation exercise from a programming exercise. It also enables a modeler to repeatedly perform simulations and to conduct a series of simulation experiments with slight parameters variations in a quick and easy manner.

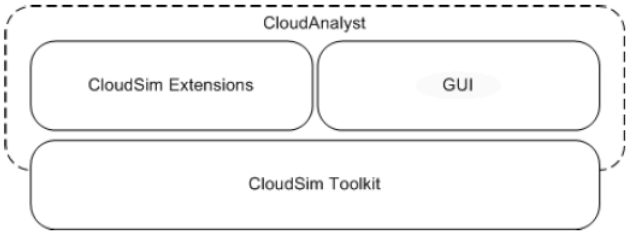

Fig. 2 Architecture of CloudAnalyst

C. *SPECI*

Based on SimKit [4], Sriram in his work [32] proposed a Simulation Program for Elastic Cloud Infrastructures (SPECI) which can simulate the performance and behavior of large data centers under the input of the size and middleware design policy as input. This simulation tool is composed of two packages, one refers to the data center layout and topology, and the other one consists of the components for experiment execution and measuring.

D. *GreenCloud*

Different from CloudSim, Kliazovich [17, 19] proposed a new simulator GreenCloud which is a packet-level cloud computing data center simulator designed to evaluate the energy costs of data centre operation. This simulator is an extension to the network simulator Ns2 [33], the architecture of the GreenCloud simulation environment is shown in Fig.3.

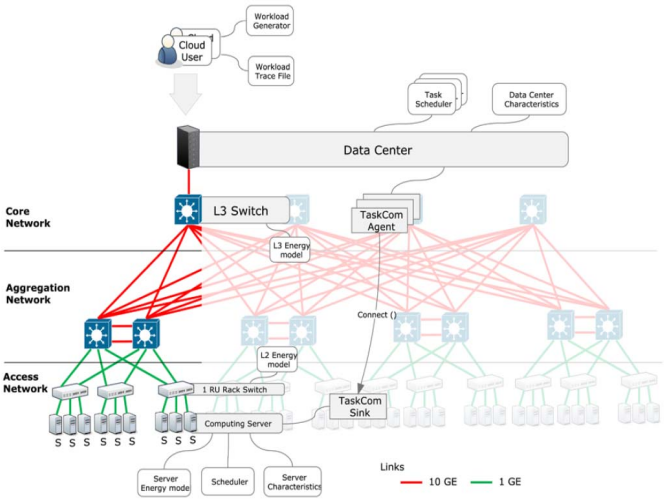

Fig. 3 Architecture of the GreenCloud simulation environment

E. OCT

Open Cloud Testbed (OCT) was proposed by Grossman et al.[16] to mainly benchmark different cloud computing systems, to investigate their interoperability. It is currently configured as a smaller-scale testbed, the architecture of OCT is shown in Fig.4.

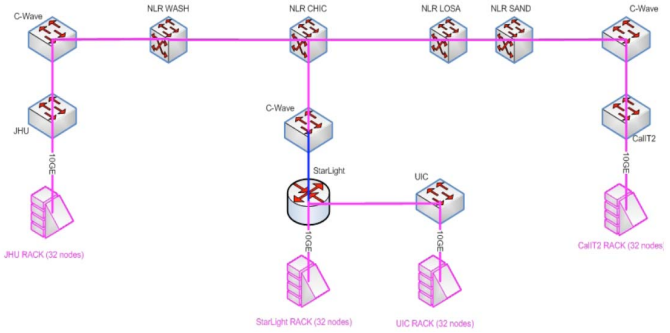

Fig. 4 Architecture of OCT

F. Open Cirrus

Open Cirrus testbed [1, 11], as shown in Fig.5, is a joint initiative sponsored by Hewlett-Packard (HP), Inter, and Yahoo! in collaboration with many organizations. Unlike CloudSim, CloudAnalyst, SPECI and GreenCloud, Open Cirrus is an open cloud-computing testbed designed to support research into the design, provisioning, and management of services at a global, multi-datacenter scale. This testbed has four main goals: foster systems-level research in cloud computing, encourage new cloud computing applications and applications-level research, offer a collection of experimental data, develop open source stacks and APIs for the cloud. Open Cirrus is a platform for real-world applications and services.

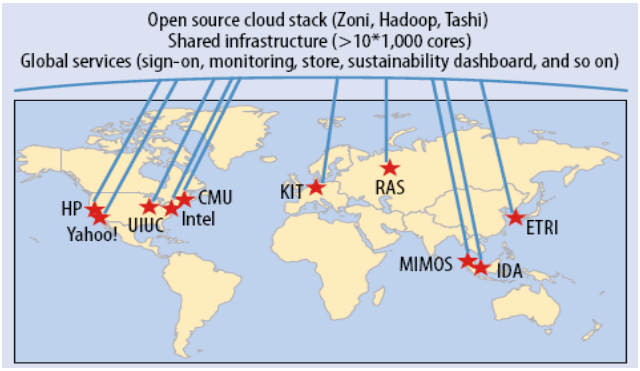

Fig. 5 Open Cirrus testbed

G. GroudSim

Ostermann et al. [28] proposed an event-based simulator GorudSim for scientific applications on grid and cloud environment that requires one simulation thread only. This simulator focuses on the IaaS area of cloud computing and is easily extendable to support additional models like cloud storage or platform as a service. Later, Ostermann et al. [27] further investigated the integration of the GroudSim simulator into the ASKALON [14] environment to allow the user to execute simulation experiments from the same environment used for real applications.

H. NetworkCloudSim

Garg et al. [15] extended CloudSim and proposed a simulation framework NetworkCloudSim which supports modeling of real cloud data centers and generalized applications such as HPC, e-commerce and workflows. The architecture of CloudSim-based NetworkCloudSim is shown in Fig.6.

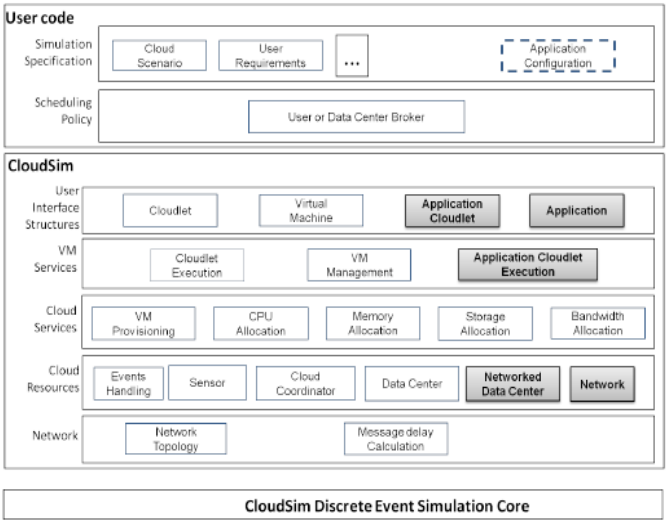

Fig. 6 Architecture of CloudSim-based NetworkCloudSim

I. EMUSIM

In order to better predict service's behavior on cloud platforms, Calheiros et al. [8] developed an integrated architecture which is built on top of two software systems: Automated Emulation Framework (AEF) [7] for emulation and CloudSim for simulation [9]. The internal organization of EMUSIM is shown in Fig.7.

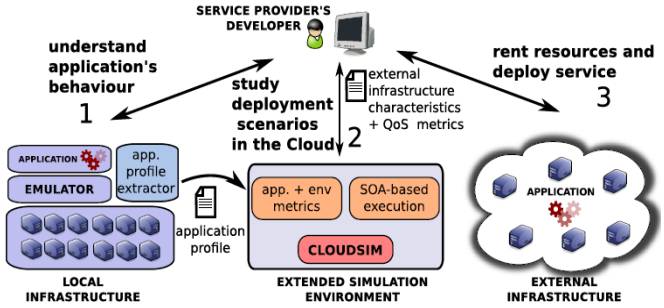

Fig. 7 Internal organization of EMUSIM

J. DCSim

To fulfill the need for simulation tools to allow rapid development and evaluation of data centre management techniques, Tighe et al. [34] proposed a Data Centre Simulator (DCSim) which is an extensible simulation framework for simulating a data centre hosting an IaaS cloud. The architecture of DCSim is shown in Fig.8.

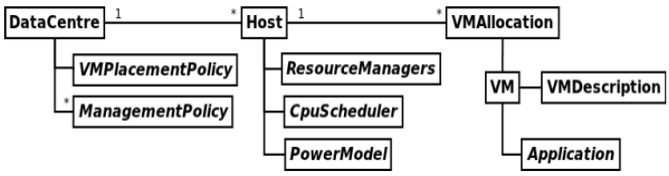

Fig. 8 DCSim architecture

K. *iCanCloud*

Very recently, nunez et al. [25, 26] proposed a simulation platform iCanCloud which aimed to model and simulate cloud computing systems. As stated in nunez et al.'s work, iCanCloud is designed based on SIMCAN [24], and can conduct large experiments, provide a flexible and fully customizable global hypervisor, simulate Amazon instance types. Fig.9 shows the layered architecture of iCanCloud.

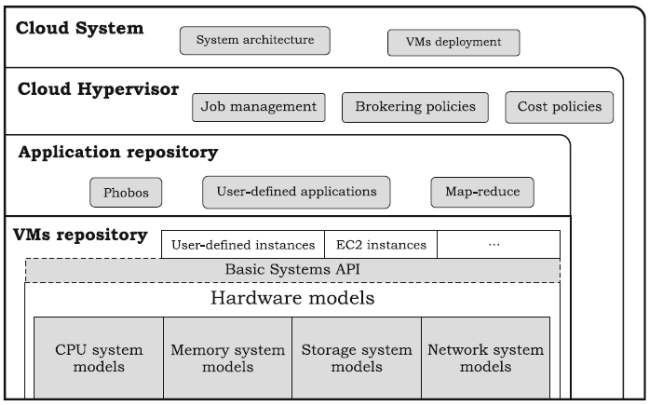

Fig. 9 Layered architecture of iCanCloud

IV. DISCUSSIONS

Cloud computing is a hot topic all over the world in the past few years. As the adoption and deployment of this technology, it is gradually considered important to evaluate its performance and security problems. Fortunately, Modeling and simulation technology is very suitable for solving this issue. As described in section III, many cloud computing simulation tools were proposed in the literature. In this section, as shown in Table I, we make analysis and comparison on the cloud computing simulators from three aspects: underlying platform that simulators are based on, developing language that simulators used, software or hardware that simulators is designed as.

From the TABLE I, we can see that cloud computing simulators in the literature can be categorized into two types, that is, simulators designed as software and simulators based on software and hardware, and meanwhile most of these simulators are software and developed using Java. We hope our work can give a reference for researchers and developers of cloud computing simulators, and more simulators are designed which are more suitable for evaluating performance and security issues of cloud computing and the application on top of it. Due to page limitations, we will make deeper analysis and comparison of these cloud computing simulators in the future work. Moreover, it is also our next work to design new cloud computing simulator.

TABLE I. COMPARISON OF CLOUD COMPUTING SIMULATORS

Simulator	Underlying Platform	Programming Language	Software or Hardware
CloudSim [9, 10]	GridSim [5]	Java	Software
CloudAnalyst [37, 38]	CloudSim	Java	Software
SPECI [32]	SimKit [4]	Java	Software
GreenCloud [17, 19]	Ns2 [33]	C++ OTcl	Software
Open Cloud Testbed [16]	Multi-site heterogeneous clusters	—	Both software and hardware
Open Cirrus [1, 11]	Federation of heterogeneous data centers	—	Both software and hardware
GroudSim [28]	—	Java	Software
NetworkCloudSim [15]	CloudSim	Java	Software
EMUSIM [8]	AEF [7] CloudSim	Java	Software
DCSim [34]	—	Java	Software
iCanCloud [25, 26]	SIMCAN [24]	C++	Software

V. CONCLUSIONS

During the past few years, cloud computing has been one of the fastest growing parts in IT industry. Users have express concern about security problems that exist with the widespread implementation of cloud computing. It is extensively necessary to evaluate performance and security risks cloud computing confronts, and thus can find more effective solutions to security issues raised by cloud computing applications. Nowadays, simulation-based approaches become popular in industry and academy to evaluate cloud computing systems, application behaviors and their security. In this paper, we summarize the existing results on modeling and simulation of cloud computing to the best of our knowledge, and analyze and compare the features of cloud computing simulators.

ACKNOWLEDGMENT

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