# A Features-based Comparative Study of Cloud Computing Simulators

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**Abstract**

Cloud computing has emerged during last decade and turned out to be an essential component for today's business. Therefore, many solutions are being proposed to optimize the cloud computing environment. Cloud simulator is required to design, test and validate proposed solutions before deploying in real cloud infrastructure. In this paper, we have discussed modern cloud simulators and presented comprehensive comparison based on their features.

***Keywords:***

*Cloud computing, Simulation, Cloud Simulator, Cloud performance analysis, Simulator features*

## 1. Introduction

Cloud introduced a new way of distributed computing by providing users with on-demand access to resources with minimal efforts and management overheads [1]. Furthermore, it offers the cost-effective solution for utilizing computing resources and, at the same time, a good attractive business for the enterprises who own computing resources for rent. Cloud computing provides many features including adaptability, accessibility, cost reduction, flexibility, reliability, and scalability [2]. According to National Institute of Standards and Technology (NIST), cloud ensures the five important features that are "on-demand self-service, broad network access, resource pooling, rapid elasticity and measured service" [3]. Besides this, the goal is to provide on-demand computing services with the guarantee of reliability, availability and scalability. Cloud provides three basic service models named as "SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service)" [4] and is deployed in four ways known as "Public, Private, Community and Hybrid Clouds". Fig. 1 summarizes the cloud services and deployment models [5].

The simulation of newly developed applications, algorithms, and architectural components is essential before deploying in a real cloud environment to analyze the behavior and improvements. Therefore, cloud simulators play an important role and facilitate researchers for rapid evaluation of the efficiency, reliability, and functioning of proposed algorithms on the big heterogeneous cloud infrastructure [6][7]. Many cloud simulators are available out of which some are commercial and some are open source. These simulators emphasis on the simulation of specific cloud computing components. For example, some targets the simulation of large-scale data centers, some of them simulates the cloud applications and analyze their behavior and some focuses on the workload distribution and fault tolerance analysis. [8][9][10] compares the cloud simulators but they do not impart the simulation focus and in-depth analysis of features provided by the simulation tools. This paper reviews modern cloud simulators in order to explore their features and limitations.

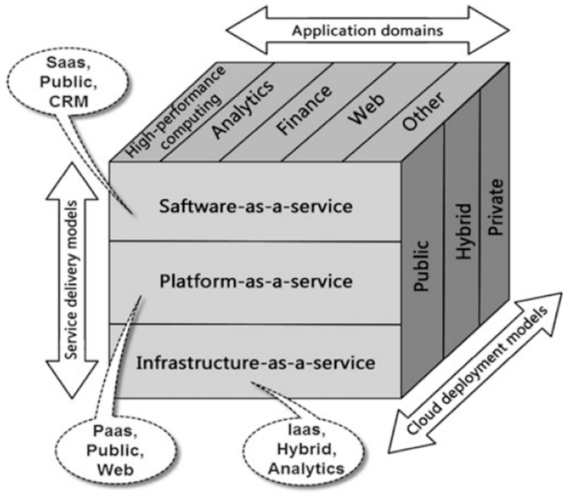


**Fig. 1**: Cloud Computing Services and Deployment Models

The rest of the paper is structured as follows. Section 2 followed by an introduction, discusses the issues related to performance analysis in cloud computing. Section 3 gives the overview of modern cloud simulators. In section 4, we have provided the detailed analysis and feature based comparison of these simulators. Section 5 concludes the paper.

Manuscript received August 5, 2025
Manuscript revised August 20, 2025
https://doi.org/10.22937/IJCSNS.2025.25.8.21

## 2. PERFORMANCE ANALYSIS AND ISSUES IN CLOUD COMPUTING

For evaluating the cloud system performance, one of the key performance requirements is to assure that it is SLA- driven system performance [11]. To determine the cloud performance, the major challenges in large-scale cloud computing are massive scalability, dynamic configuration, and complexity of component interactions. The cloud systems are managed dynamically by SLAs that are settled an agreement between cloud consumer and service provider for service usage and policies. The performance metric for SLA is response time that deals with a response time of requested services to be delivered.

Cloud users connect through the internet with cloud and service components in the cloud are located at multiple hosts that may be in federated clouds. The delivery of services to users generated different types of execution and delivery paths that become complex and challenging to determine cloud behavior for performance analysts. An example for such challenge is to identify the service component that causes the main problem when system performance is not satisfying the expectations.

Cloud storage and evaluating its performance is very critical in terms of security, reliability, and availability because it contains the valuable business data. A 10-point execution assessment structure for existing distributed storage framework proposed in [12] is useful for the evaluation and simulation of distributed storage.

## 3. CLOUD SIMULATORS

Cloud computing evolved in last few years and facilitates with a new way of delivering on-demand computing services. The evolution roots of cloud computing are in Grid Computing and Cluster Computing. Academic and industrial researchers are participating in this field as it is yet evolving. For deploying cloud infrastructure, cloud services, policies related to service delivery and users for example SLA (Service Level Agreement), energy efficient computing, risk management and related policies, load balancing, communication between components and federated clouds, QoS etc. requires cloud simulators for researchers to test, evaluate and improve their idea and findings before actual implementation in real clouds. There are few cloud simulators available that offer different features to researchers for simulation of some aspects of clouds. The list below is the names of modern cloud simulators and we will discuss and compare them in proceeding sections.

*A.* CloudSim
*B.* CloudAnalyst
*C.* GreenCloud
*D.* iCanCloud
*E.* DCSim
*F.* MDCSim
*G.* NetworkCloudSim
*H.* EMUSIM
*I.* SPECI
*J.* D-Cloud
*K.* eXo Cloud-IDE
*L.*

### 3.1 CloudSim

CloudSim, with the latest release of version 3.03 at May 2, 2013, is a simulation and modeling framework for cloud services and infrastructure, developed by the "University of Melbourne's Cloud Computing and Distributed Systems (CLOUDS) Laboratory". Its development started with the motivation of providing a simplified, comprehensive and extensible structure to the researchers, developers and cloud analyst for modeling, simulation, experimentations and performance analysis [13]. The main advantages of CloudSim are time effectiveness, flexibility, and applicability. It facilitates the researchers to seamlessly perform experiments and investigate results focusing towards the certain system design issues regardless of low-level infrastructural implementation details of cloud computing. CloudSim eases to model and simulate large-scale data centers, host server's virtualization with customizable policies for resource provisioning, topologies for data centers, applications that use MPI (Message Passing Interface) and federated clouds. It further offers run-time inclusion of simulation components with stop and resumes feature. Defining user-defined policies enables provisioning of resources and to analyze it [14].

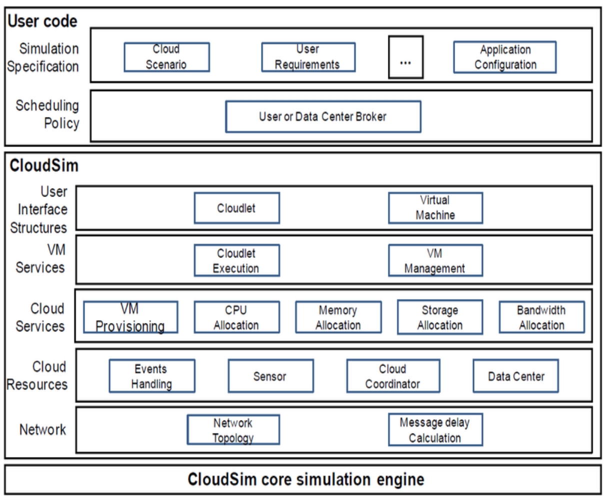

**Fig. 2**: Architecture of CloudSim [13]

CloudSim has the layered architecture and existing simulation libraries of GridSim and SimJava are exploited for development. As shown in Fig. II, the first layer is User Code that allows cloud application developers to configure applications, design scenarios for cloud availability and testing, and implement policies for resource provisioning. It contains basic user-level entities such as the number of machines including specifications, required applications, virtual machines, the number of users and policies etc. The most important layer, CloudSim layer is the simulation layer that contains "user interface structures, virtual machine services, cloud services, cloud resources and network implementation details". CloudSim has the following main components:

- Data center cops the core cloud services. It comprises a set of host entities that are allocated to virtual machines using allocation policy. VMs perform the "low level" processing. Minimum one data center need to be created for simulation.
- Host referred to a computing server that has the processing power, memory, storage and authority for assigning processor cores to virtual machines from a pool of VMs managed by the host.
- The provisioning of virtual machine is the assignment of different VMs to different hosts. These are assigned so that host can schedule processing cores to virtual machines. This assignment of VM depends on the application, and the default policy is "First-Come-First-Serve".
- Datacenter broker plays a role between users and service providers to identify the best provider for user subject to conditions of QoS imposed by the user.
- Cloudlet component of CloudSim signifies the application service whose complexity is modeled in terms of the computational requirements.
- CloudCoordinator is responsible for communicating with other CloudCoordinator, services, and brokers. Furthermore, it observes the internal state of a data center periodically.
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### 3.2 CloudAnalyst

CloudAnalyst is a visual tool for analyzing the cloud computing environment and applications. It is developed based on CloudSim [14]. The motivation behind CloudAnalyst was the unavailability of tools that can help to estimate the requirements related to the workload on computing servers and user for geographically distributed cloud applications [15]. This requirement and performance analysis are important because cloud contains a distributed infrastructure and applications may run in different geographical locations. This distribution of application effects the performance. CloudAnalyst enables to analyze the performance of extensive cloud applications based on various deployment setups by simulating them.

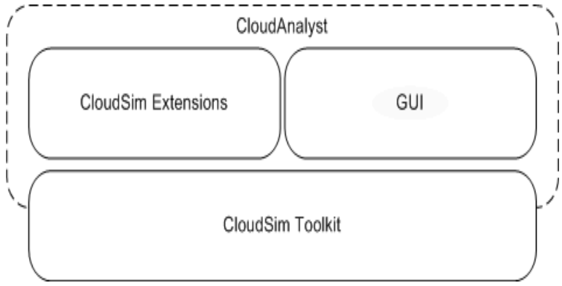


**Fig. 3:** CloudAnalyst Architecture [15]

The CloudAnalyst is built with the extensions of CloudSim Toolkit as shown in Fig. 3. It extends the GUI package to ease with separation of programming and simulation exercises. The existing CloudSim libraries are used to model the simulation and analysis of applications behavior. CloudAnalyst has the following main components:

- GUI Package: The front-end is the graphical user interface to control screen transitions and related functionalities.
- Simulation: This important component enables the development and execution of simulation by retaining the simulation parameters.
- UserBase: It is used to model the users and users' traffic.
- DataCenterController: This module tackles with the activities related to the data center.
- Internet: This is used to exhibit the Internet and traffic routing.
- InternetCharacteristics: This is used to define the Internet characteristics that is used for simulation including latency, bandwidth, and region etc.
- VmLoadBalancer: Used to implement the load balancing policies for data centers.
- CloudAppServiceBroker: This defines the cloud service broker who is responsible for managing traffic and service delivery between user and service provider.

### 3.3 GreenCloud

The absence of a meticulous simulator accessible in the market was the inspiration to develop GreenCloud that enables researchers to watch, communicate and measure cloud executions. GreenCloud is a modern open source cloud computing simulator which has been expounded with regards to the GreenIT and ECO-Cloud projects [16].

GreenCloud is NS2 (Network Simulator) simulator that focuses the packet-level simulation of cloud data centers for energy-aware computing [17]. It enables the simulation of workload distribution along with acquiring the information related to energy utilized by data center components including servers, switches, and links. Furthermore, it simulates the packet level communication patterns. Fig. 4 elaborates the architecture of GreenCloud.

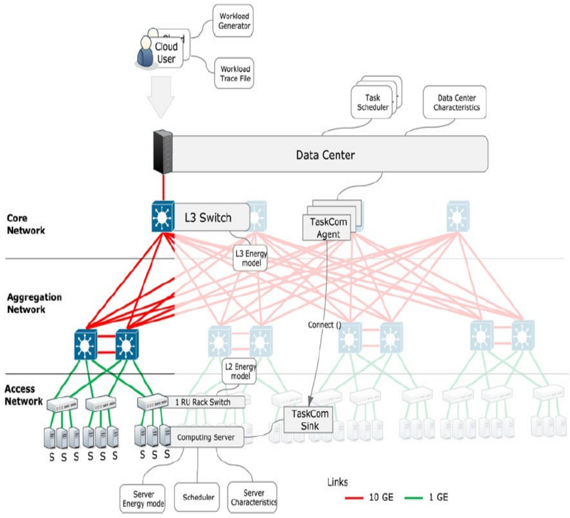


Fig. 4: GreenCloud Architecture [17]

The architecture of GreenCloud is deployed on the basis of three-tier network architecture. Data Center layer is added on top of core network layer which provides an interface for cloud users. The components of Data Center layer are Data Center Characteristics and Task Scheduler. Data Center Characteristics is used to define the data center and Task Scheduler is responsible for schedule and workload distribution. At the "core network, aggregation network and access network layers", TaskCom Agent are responsible for routing and communication between computing servers, switches and data center components. These layers also contain the L3 and L2 energy model to capture the energy consumed by layer 3, layer 3 and rack switches. For each computing server, there is a scheduler for scheduling computing tasks, an energy model to capture energy consumed by server and server characteristics component to define the server capabilities.

## 3.4 iCanCloud

iCanCloud is an adaptable and scalable cloud computing simulation tool intended for modeling and mimicking the large cloud environments both existent and fictional cloud architectures. It was developed by the "Computer Architecture, Communications and Systems (ARCOS) Research Group at Universidad Carlos III de Madrid, Spain" [18]. It provides the valuable information to users about expenses by forecasting the trade-offs between price and performance of specific applications running on certain hardware. iCanCloud can be utilized by a variety of clients, from basic active users to developers of large distributed applications.

iCanCloud has a layered architecture [19] as elaborated in Fig. 5. The lowest layer contains the hardware models such as "CPU, memory, storage and network system". It also contains the basic systems API that is responsible for providing and interface between hardware models and applications. The second layer is VMs repository layer on top of hardware models. It is an essential element for creating cloud system and contains the list of previously created virtual machines and Amazon EC2 VM instances. The application repository layer, on top of VMs repository layer, contains the pre-defined cloud applications that can be customized by users. The cloud hypervisor layer contains three components: 1) job management manages the incoming jobs and VMs instances where the job is performed, 2) brokering policies to define policies related to brokers and 3) cost policies to define the cost of utilized resources. The topmost layer is the cloud system layer that defines the architecture of cloud and deployment of virtual machines.

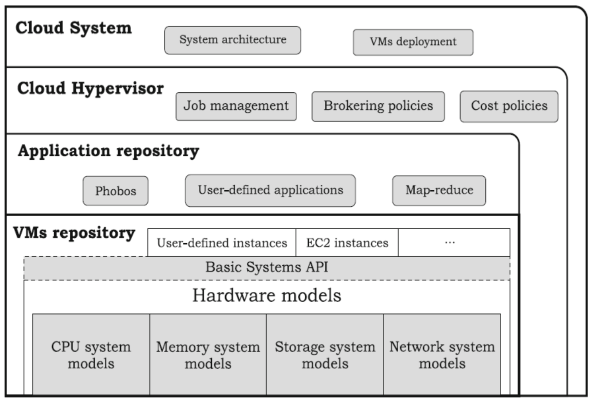


Fig. 5: Architecture of iCanCloud [19]

## 3.5 MDCSim

MDCSim is an adaptable and scalable simulation toolkit for comprehensive evaluation of multi-tier data centers [20]. It mainly focuses the simulation of three-tier clustered datacenters. MDCSim is comprehensive because all characteristics of a multi-tier data center are implemented in detail. It is flexible as different characteristics of the data center can be manipulated. For instance, users have provision to change the number of tiers, customize the algorithms for scheduling, and alter the communication mechanisms and interconnects.

CSIM [21] is the underlying platform for MDCSim and the simulation is constituted into three layers called "communication layer, kernel layer, and user-level layer". Fig. 6 gives an overview of MDCSim platform.

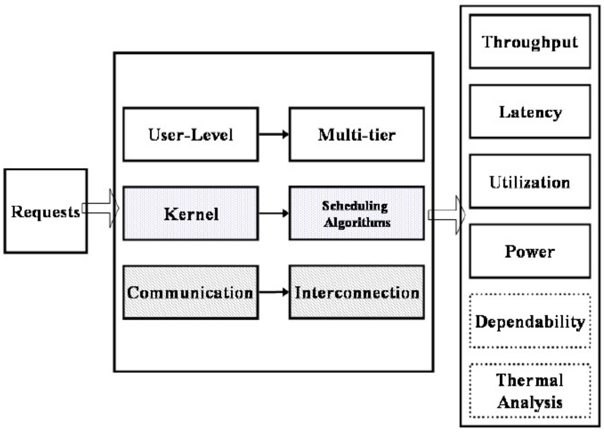


**Fig. 6:** Overview of Multi-tier Simulation Platform

## 3.6 DCSim

DCSim is a datacenter simulator for assessing management of dynamic virtualized resource [22]. It is an event-driven simulation tool that aims to simulate IaaS offering of a data center to various clients. It focuses on modeling transactional, continuous workloads (such as a web server), but can be extended to model other workloads as well. The foundation of the DCSim development has many motivational reasons including the unavailability of customizable and extensible simulation tool for, modeling multi-tenant data centers, simulating the interactions and dependencies between many VMs, resource management, VM migration and modeling of host power states. Furthermore, it enables the computation and recording of SLA violation, active host, host hours, active host utilization, the number of migrations performed, power consumption, and simulation and algorithm running time.

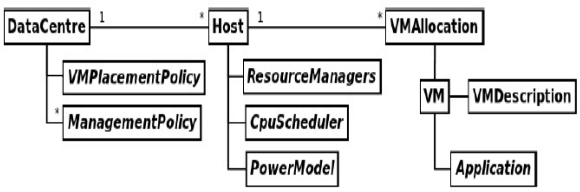


Fig. 7: Architecture of DCSim [22]

Fig. 7 gives an overview of the architecture of DCSim. The key class is termed as DataCenter that contains hosts, virtual machines and various components for management and defining policies. A host is a collection of VMs who is responsible for hosting the task and a data center consists of many interconnected host machines. The responsibilities of the host include VM allocation, resource management, CPU scheduling and power consumption modeling.

## 3.7 NetworkCloudSim

NetworkCloudSim is an extension of CloudSim to model the parallel applications in real networked data centers [6]. Particularly, it addresses the problems and solutions with respect to modeling the internal network and applications of a data center. Furthermore, it supports applications with communicating elements or tasks such as MPI and workflows. In NetworkCloudSim, there are three main actors called Switch, NetworkDatacenter and NetworkDatacenterBroker as shown in Fig. 8. There are two main components of NetworkCloudSim, one of which contains the Switch, NetworkPacket and HostPaket classes for modeling a network topology within the data center. The second component contains the NetworkCloudlet and AppCloudlet classes for application modeling and simulation between different tasks.

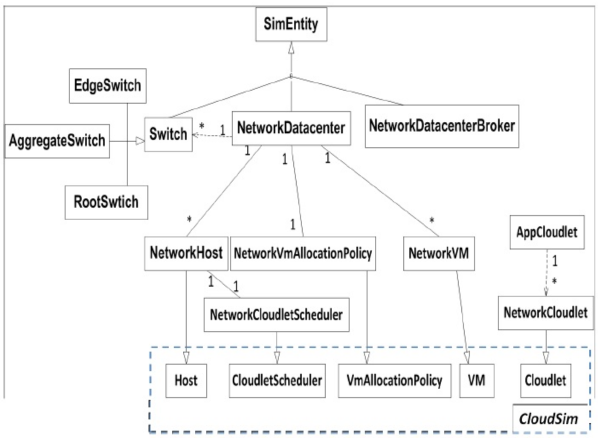


Fig. 8: NetwrokCloudSim Class Diagram [6]

## 3.8 EMUSIM

EMUSIM is targeted to support the public cloud providers for simulation and analyzing the behavior of cloud applications. It is an incorporated emulation and simulation tool for modeling, assessment, and confirmation of the execution of cloud computing applications [23][24]. Fig. 9 gives the overview of EMUSIM. It uses Automated Emulation Framework (AEF) [25] for automatically extracting information from the application performance. This extracted information is then used to model the simulation and CloudSim are used for the simulation. It also uses the QAppDeployer [26] – a QoS-aware application deployer – for load generation and automated application deployment to virtual machines. Emulation empowers the execution of the authentic application in a limited environment that models the concrete creation framework, while, simulation permits evaluation of how a system/application acts light of various conditions.

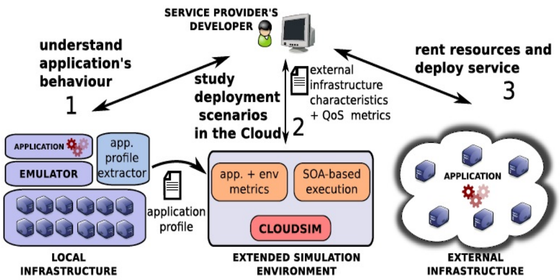

Fig. 9: EMUSIM Overview [23]

### 3.9 SPECI

SPECI is a simulator for resilient cloud infrastructures that aims to explore the facets of scaling and performance properties of cloud-scale data centers [27]. SPECI is built on two packages, where first specifies the layout and topology of a data center, and second comprises of the elements execution of various experiments and evaluating the results. The data center layout package is a collection of classes for each type of component that is part of the data center, for instance, nodes and network links. This is used to design the layout and topology of the data center for observation and experiments of interest. The experiment component of the SPECI uses SimKit [28] for testing and recording results. The latest public release is named as SEPCI-2 [29] in which the data center layout is structured in a hierarchical fashion.

### 3.10 D-Cloud

D-Cloud facilitates with a parallel software testing environment for reliable distributed systems that uses cloud computing technology and VMs with the facility of fault instillation [30]. D-Cloud supports the fault tolerance analysis related to the failures of hardware that happen in the computing machine. For this, the virtual machine layer of D-Cloud offers the facility of fault injection. Furthermore, it enables to manage computing resources flexibly and automatically, for instance, simulation test can be performed quickly by simultaneous use of resources if available. Moreover, it automates the process of system setup including fault instillation based on test scenario provided by the tester. Additionally, it automates testing phenomena by utilizing the descriptions for system configuration, and test-cases to perform tests on cloud computing systems.

The design of D-Cloud exploits QEMU [31] for virtualization and Eucalyptus [32], [33] for mimicking cloud environment to manage the computing resources. D-Cloud has three components namely, QEMU nodes, Controller node, and Frontend as depicted in Fig. 10.

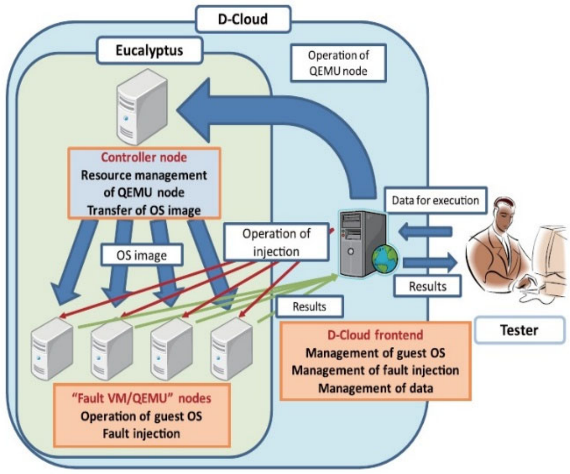

Fig. 10: Architecture of D-Cloud [30]

### 3.11 eXo Cloud-IDE

eXo IDE [34] is a web application that facilitates with an extensive test environment to develop various scripts, content, and services. The advantage of using eXo is that, it does not need installations, it runs in a browser and facilitate for retrieving and operating files online. It is capable of working with remote file system with the help of virtual file system (VFS). Additionally, it provides code editor enriched with popular programming languages such as HTML, XML, Java, PHP, Ruby and JSP for designing and testing applications. Furthermore, it includes many tools for client-side and server-side application development. Also, it facilitates with the deployment of services using "sandbox" technique.

## 4. DISCUSSION

There are some simulators available for simulating cloud environment that we have discussed above. These simulators have some common and distinct features along with providing the environment for the different type of simulations. For instance, CloudSim focuses the simulation of large-scale data centers, host server's virtualization with customizable policies for resource provisioning, topologies for data centers, applications that use MPI and federated clouds. CloudAnalyst emphasis on the cloud applications behavior. GreenCloud cover the simulation of the data center with respect to energy consumption. iCanCloud aims to forecast the trade-off between price and performance.

MDCSim focuses the simulation of multitier data center applications while DCSim covers the workload and VM management. The NetworkCloudSim emphasis on the internal network of data centers. EMUSIM targets the evaluation of cloud applications behavior. SPECI explores the requirements for scalable data centers. D-Cloud focuses the analysis of fault-tolerance in hardware and eXo Cloud-IDE provides the environment for designing and testing the cloud applications. Table I gives the summary of these cloud simulators with respect to simulation emphasis.

TABLE I
SUMMARY OF CLOUD SIMULATORS

| Simulation Tool | Simulation Focus |
|---|---|
| CloudSim | Large-scale data centers, host server's virtualization with customizable policies for resource provisioning, topologies for data centers, applications that use MPI and federated clouds. |
| CloudAnalyst | Analysis of the behavior of extensive cloud applications with a geographical distribution that affects the application performance. |
| GreenCloud | Workload distribution with gathering information of energy utilized by datacenter components. Packet level communication pattern in cloud data centers for energy-aware computing. |
| iCanCloud | Forecasting the trade-offs between price and performance of applications running on certain hardware. |
| MDCSim | Multi-tier clustered datacenters for applications deployment and communication. |
| DCSim | Modeling of transactional and continuous workloads with VM management in a data center providing an IaaS. |
| Network CloudSim | Modeling of data centers' internal network for parallel applications and communication. |
| EMUSIM | Modeling, evaluation, analysis and validation of performance and behavior of cloud computing applications for the public cloud providers. |
| SPECI | Exploring the requirements of scaling for elastic cloud infrastructures and performance properties of cloud-scale data centers. |
| D-Cloud | Fault tolerance analysis related to hardware failures and cloud applications. |
| eXo Cloud-IDE | Designing and testing applications. Accessing and online manipulation of files. |

These simulators have a different underlying platform and are written in different programming languages. Some of them are open source while some are available for commercial purposes. Table II gives the comparison of different features provided by current cloud simulators.

## 5. CONCLUSION

Simulation is extremely important in order to validate cloud applications, protocols, and infrastructure. During last decade, many cloud simulators have been proposed by the academic and industrial researcher to simulate cloud environment. These simulators emphasis on simulating different components of cloud including applications and their behavior, data centers, virtualization, workload balancing, and internetworking of data center components. Some of them support federation but up to the best of our knowledge, none of the simulators support the simulation of multiple clouds with different ownership, administration, and policies at the same time. The multi-cloud simulation is important if we need to design and validate the cross-cloud communication models, intercommunication, sharing of resources and sharing of attacks' information to protect clouds from same attacks.

TABLE II
FEATURE-BASED COMPARISON OF CLOUD SIMULATORS

| | CloudSim | Cloud Analyst | GreenCloud | iCanCloud | MDCSim | DCSim | Network CloudSim | EMUSIM | SPECI | D-Cloud | eXo Cloud-IDE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Platform | GridSim | Cloud Sim | NS2 | OMNET | CSIM | - | CloudSim | AEF, CloudSim | SimKit | Eucalyptus/ XML | Web-based |
| Programming Language | Java | Java | C++/Otcl | C++ | C++/Java | Java | Java | Java | Java | Java | - |
| GUI Support | No | Yes | Limited | Yes | No | No | No | Limited | No | No | Yes |
| Availability | Open Source | Open Source | Open Source | Open Source | Commercial | Open Source | Open Source | Open Source | Open Source | Open Source | - |
| License | LGPL | LGPL | GPL | GNU | - | GPL | LGPL | GPL | - | GNU | - |
| Federation Support | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | - | Limited | Limited |
| Multi-Cloud Simulation | No | No | No | No | No | No | No | No | No | No | No |

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