CLOUD SIMULATORS – AN EVALUATION STUDY

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Abstract: *Cloud Computing support better computation through improved resources utilization and reduced infrastructure costs. Number of big providers like Google, Oracle, and Amazon sell services of Cloud Computing which are managed by Cloud Management Systems. It is very difficult to setup research on live cloud environments for individuals and small institutions due to the costs involved in setting up a cloud. Thus, Cloud Simulators are a cost effective way to study cloud components behavior and performance against different situations and work load. Several Cloud Simulators were developed over the years and this paper presents an evaluation study of most of them. We discuss the common architecture of Cloud Simulators. Then we evaluate 33 Cloud Simulators based on different criteria. The results are discussed. We are showing different capabilities, suitability for problems, and extendibility of the studied Cloud Simulators.*

Keywords: *Cloud Computing, Cloud Simulator, Simulation Tools, Modeling Framework.*

ITHEA Keywords: *I.6 SIMULATION AND MODELING, I.6.8 Types of Simulation*

Introduction

Cloud Computing is a trend all over the world and people today are shifting towards it from traditional computing. This is due to the promise of cost reduction, greater flexibility, elasticity, scalability, on-demand access, resource utilization, minimal infrastructure management, and location independence [Lokesh et al., 2015]. Cloud Computing can be defined as the computing concept that involves a large number of computer connected through a real-time communication network such as the internet [Alam et al., 2015]. Cloud Computing applications range from science to engineering, gaming, and social networking. In scientific applications domain, Cloud Computing is applied to High Performance Computing (HPC) [Ekanayake and Fox, 2009], High Throughput Computing (HTC) [Rho et al., 2012], and data intensive applications [Shamsi et al., 2013]. In Healthcare domain, Cloud Computing is supporting doctors to provide more effective diagnostics [Kumar and Chaithra, 2015] and building healthcare monitoring systems [Deepa and Boopathy, 2014]. In Biology, Cloud Computing is helping in prediction of protein structure [Li et al., 2012], designing new drugs for the treatment of diseases [Nony et al., 2014], and supporting Gene Expression Data Analysis for Cancer Diagnosis [Vecchiola et al., 2009]. While, in geoscience domain, Cloud Computing is supporting in satellite image processing [Golpayegani and Halem, 2009]. At last from the business domain, Cloud Computing is supporting Customer Relationship Management (CRM) [Shaqrah, 2016] and Enterprise Resource Planning (ERP) [Saini et al., 2011] systems.

There are many service providers available for the cloud. Cloud Services are provided to end users using a standard pay-as-per-use model. Organizations have to take a decision which service provider's services are more advantageous to the organization. The cost of purchasing the services from different service providers leads to increased budget and wastage of time. A comprehensive study of advantages and disadvantages of Cloud Computing in the real Internet platform is very expensive and difficult. This requires interaction with several computing and network elements that cannot be controlled or managed by application developers.

In addition, the service providers themselves need to examine the proposed updates to their service before getting them applied. They don't need to apply the changes and then being faced with issues due to related aspects not covered during the design. Before real-time implementation, system administrators, cloud specialists, and researchers need to measure performance and check all security issues. Moreover, Service Providers need to examine the services from time to time [Lokesh et al., 2015]. Real-time evaluation proves to be costly and impractical, so simulation offers an easy way out to handle this evaluation.

To solve these problems, Cloud Simulation tools have been developed to study and evaluated of cloud computing technology. These tools include different algorithms and models, so organizations and service providers can change them to meet the problem resolution before investing in hardware and software. Cloud Simulators allow to change input very easily as when needed, which provide better results. In addition, they do not need the deep knowledge to use for setting up and experimenting a simulated cloud.

But getting the right tool for a given scenario or knowing what features each tool has is a challenging and complex task. It is necessary to perform a comprehensive survey and critical evaluation of them. This paper evaluates some of the Cloud Simulators used for the purpose of simulation and modeling of Cloud Computing. In next we discuss the background and related work. While, the section after presents the common architecture of Cloud Simulators. Then, we provide the evaluation criteria of the selected Cloud Simulators and finally we present conclusion and future work.

Background

Cloud Computing is considered as a virtual pool of computing resources. It provides a whole dynamic computing system for application environment to the users. Cloud Computing environments have specific characteristics such as heterogeneity, dynamicity, and scalability which require particular research tools [Lokesh et al., 2015]. Performing real cloud experiments are challenged with some limitations on software and hardware reconfiguration and rescaling which impede performance of the whole system. Service providers and researchers need to tune their proposed Cloud Computing method under different scenarios and varying number of resources/users to realize its potential before using in a real environment.

Simulation is a science and technique to make a model of process or a real system, it is designed to evaluate and test strategies. Simulation aims to study and understand the behavior of the system or evaluating various strategies [Ingalls, 2008]. Simulator plays the role for designing a model of a real system and conducting experiments with this model [Das et al., 2014]. The model is used later on for the purpose of either of understanding the behavior of the system or of evaluating various strategies for the operation of the system [Buyya et al., 2009].

Salama et al. [Salama et al., 2013] proposed a generic framework for modeling and simulation of Cloud Computing Services. They assume that the Cloud Simulation Framework needs to fulfill the following functional requirements: (1) Support a list of quality metrics, from which the user will select his preferences, is carried out, (2) Support solver for user problems like optimum service select, (3) Dynamically run the simulation, (4) Set preferences for different criteria and use the preferences to run any service related problem, (5) Application should also display a graphical representation for the final calculations, as well as intermediate results, and (6) The system should allow the decision makers to repeat their experience under various parameters.

From the other hand, Oujani and Jain [Oujani and Jain, 2013] indicated that there is two types of Cloud Simulators, Cloud Simulators based on software only and Cloud Simulators based on software and hardware. They compared eight Cloud Simulators and the comparison criteria was underlying platform, programming language, and hardware/software composition. In addition, Guérout et al. [Guérout et al., 2013] provided a survey on energy-aware simulation techniques with DVFS (Dynamic Voltage and Frequency Scaling).

Sakellari and Loukas [Sakellari and Loukas, 2013] provided another way to classify Cloud Simulators into Mathematical Modeling of Cloud Systems, Cloud Simulation Software Tools, and Cloud Testbeds. They evaluated some of the existing mathematical models, Cloud Simulators and testbeds based on the criteria of energy efficiency, Quality of Service (QoS), programming language, and availability as an open source tool.

Based on the above surveys, it is shown that all the review generally provide the information about various available approaches and their features. They do not however provide clear guidelines as to which approach is suitable for a particular situation. Hence, we consider a complementary review of the existing approaches. The following sections describe the common architecture of Cloud Simulators. Then evaluation criteria is proposed and simulators evaluated.

Common Architecture of Cloud Simulators

Cloud is considered as a large pool of resources (CPU, Memory, Network Bandwidth, Disk I/O, Library … etc.) which can be accessed through set of APIs [Alam et al., 2015]. Figure 1.a shows the architecture of Cloud Computing, while Figure 1.b shows the common architecture of Cloud Simulators.

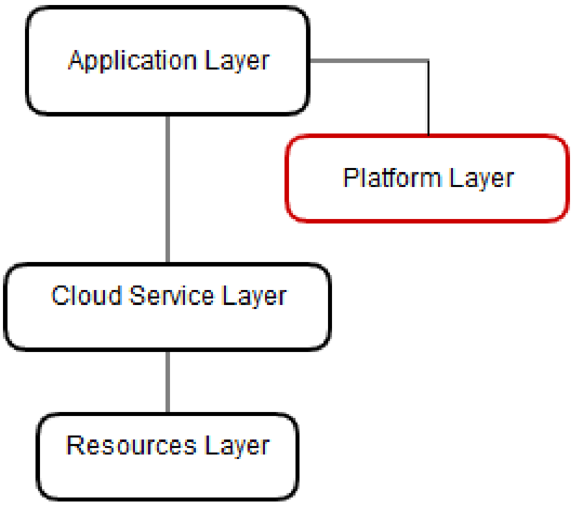

Figure 1.a Cloud Architecture

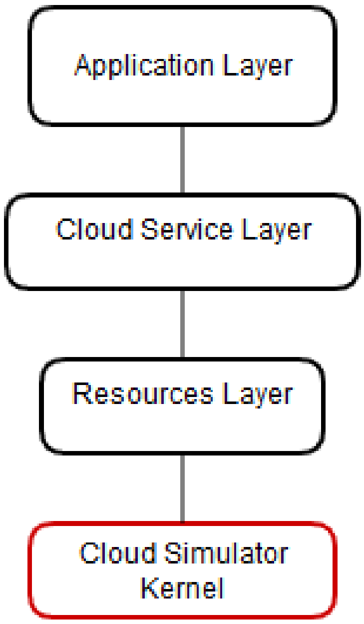

Figure 1.b Cloud Simulator Architecture

Both have four layers. Three out of the four layers are shared between Cloud Computing and Cloud Simulators and they are Resources Layer, Cloud Service Layer, and Application Layer. Resources Layer consists of the hardware devices including the CPU, Memory, Storage and Network Bandwidth which are physically resident on a server farm. Due to limited number of resources, resources needed to be utilized. To utilize the resources layer, virtualization technology is used to provide Infrastructure as a Service (IaaS). Examples of IaaS providers are Amazon Web Services [AWS, 2017] and Rackspace [Rackspace, 2017] which provides a pool of Virtual Machines (VMs) that can be provisioned based on users' requests. The Cloud Services Layer virtualizes available resources in the Cloud Computing System as stream of resources available for provisioning to users' requests. The Application Layer is the layer in which cloud users can submit their applications to the Cloud Services Layer to consume the resources. At the Application Layer service providers can provision ready-to-use software and applications for the business needs of the cloud users. Hence, this layer provides the Software as a Service (SaaS). Examples of SaaS providers are Google Apps [Google App Engine, 2017] and Salesforce [Salesforce, 2017].

Cloud Computing Architecture has a distinct layer called the Platform Layer. The Platform Layer is the Software Development Kit (SDK) which contains the interface the user application can use to communicate with the Cloud Service Layer. It simplifies the development of the Cloud Applications and contains references to call the Cloud Service Layer Application Programming Interface (APIs). This layer provides the Platform as a Service (PaaS). Examples of PaaS providers are Google App Engine [Google App Engine, 2017] and Windows Azure [Windows Azure, 2017].

At the end, Cloud Simulator Architecture has Cloud Simulator Kernel Layer which is the layer that contains the libraries that manage the simulation and its parameters. It also contains the configuration of the cloud research experiments that need to run on the virtual resources.

Evaluation Criteria and Cloud Simulators

In this section, we provide list of evaluation criteria with brief about each criteria then we discuss some available Cloud Simulators and get them evaluated based on the mentioned evaluation criteria.

Evaluation Criteria

We consider the six functional requirements of Salama et al. [Salama et al., 2013] (quality metrics, solver for user problems, dynamically run the simulation, preferences, graphical representation, and repeatability), three requirements from Oujani and Jain [Oujani and Jain, 2013] (underlying platform, programming language, and hardware/software companions), and three types of services (IaaS, PaaS, SaaS) supported from the Cloud Architecture as our first set of evaluation criteria. Additional to them, we proposed these requirements for evaluation of the Cloud Simulators as we studied the simulators:

1. **Federation Policy** is to allow Cloud Applications to run on heterogeneous clouds in different domains.
2. **Modeling of Public Cloud Providers** is to provide modeling capabilities of public cloud providers like Amazon, Oracle and Google.
3. **Migration Policy** is when, which and where to migrate a virtual machine.
4. **Security** is whether the Simulator support applying security policies on users, resources and access to the modeled system.
5. **Mobile Cloud Computing** is to support integration between Cloud Computing and Mobile Service system to offload mobile data and intensive computation requirements to the Cloud infrastructure.
6. **Desktop Cloud Computing** is to support integration with Desktop Machines to offload the intensive computation requirements.
7. **Cost Modeling** determines the price of the service usage based on a model or system policies.
8. **Communication Modeling** concerns with the costs involved in the data center communication.
9. **Energy Modeling** is to model the energy by the aim to reduce the heat produced in the data center.
10. **Power Saving Modes** are the modes for saving power consumption in data centers.
11. **Physical Modeling** is to model physical layer entities such as cache, allocation policies for memory, file system models … etc.
12. **Application Models** are the models supported by the framework for different application components.
13. **Availability** specifies whether the simulator is commercial or available as in open source.
14. **Simulation Time** determines how long the simulator takes to perform the simulation.
15. **Parallel Experiments** is to run the modeling experiments through several machines.
16. **Simulator Type** is whether the Simulator an event based or packet level. Event Based Simulators model the operations of the system as a discrete sequence of events. Packet Level Simulators analyze packets interaction between different network entities.

Cloud Simulators

1. **CloudSim [Calheiros et al., 2011]** is a complete extendible simulation tool for modeling and simulation of Cloud Computing. It allows extending and defining policies for all system components. It supports both system and behavior modeling like data centers, virtual machines and resource provisioning. It is considered the most popular Cloud Simulation tool.
2. **CloudAnalyst [Wickremasinghe et al., 2010]** is based on CloudSim and SimJava frameworks. It is developed to simulate Cloud applications with the purpose of studying the behavior of such applications under various deployment configurations. It supports configuring any geographically distributed system including information of geographic location of users and data centers.
3. **GreenCloud [Kliazovich et al., 2010]** is a packet level simulator that is specially made for energy-aware environment. It calculates energy consumption of all data center components and communication between the packet levels. It is designed to capture details of the energy consumed by data center components as well as packet-level communication patterns between them.
4. **iCanCloud [Núñez et al., 2012]** is complete simulation framework for cloud infrastructures. It is specially focused on the simulation of Amazon instance types. In addition, it allows design and implementation of a flexible hypervisor module that provides an easy method for integrating both existent and new cloud brokering policies. It can predicts the trade-offs between cost and performance of applications executed in modeled hardware.
5. **MDCSim [Lim et al., 2009]** is developed to measure performance, energy, and infrastructural availability cost for multi-tier data center simulation. It simulates data center components such as servers, switches, and communication links. MDCSim has been validated through a three tier Linux Cluster based data center connected with InfiniBand Architecture (IBA) and 10-gigabit Ethernet (10 GbE) under different conditions and cluster specifications.
6. **NetworkCloudSim [Garg and Buyya, 2011]** is an extension to CloudSim with a scalable network and generalized application model, which provides accurate evaluation scheduling and resource provisioning policies. It supports modeling complex applications with data driven applications and workflow. As it implements network flow model design with low computational overhead.
7. **EMUSIM [Calheiros et al., 2013]** is a simulator and emulator of a cloud environment based on CloudSim and Automated Emulation Framework (AEF). It is doing that by extracting information

from applications through emulation then use this information to generate the corresponding simulation model. Emulation has scalability limitations due to either hardware constraints or difficulty in generating large and realistic workloads.

8. **CloudReports [Sá et al., 2014]** is a graphic tool that simulates distributed computing environments based on the Cloud Computing. CloudReports provide different aspects for researcher to play role of service providers and users. Supported types of extensions in the CloudReports are broker policies, virtual machines allocation policies, power consumption models, virtual machines schedulers, and resource utilization models.
9. **CloudSched [Tian et al., 2013]** is a Cloud resources scheduling emulator. It helps to identify and explore the optimal solutions for different resource scheduling policies and algorithms. Different resource scheduling policies and algorithms can be compared with each other for performance evaluation.
10. **CloudExp [Jararweh et al., 2014]** is a modeling and simulation environment which introduced a specialized mobile cloud computing experimental framework. It conducts various mobility scenarios for mobile devices. It provides user-friendly GUI to enhance the users' experience in building their own infrastructure. In addition, it allows researchers to study the communication cost between users and cloud.
11. **DCSim [Tighe et al., 2011]** is developed to simulate a virtual data center. It is using centralized management and neglects the network topology. DCSim provides extra features of replicated Virtual Machines (VMs) with a multi-tier application model to simulate dependencies between VMs, VM replication as a tool for handling increasing workload.
12. **ICARO [Badii et al., 2016]** is a cloud simulator developed in the ICARO project. The main aim of this simulator is to analyze the changes on workload in a data center when the structure of workload is modified dynamically in real time. All, other simulators study change of the structure of the data center, but ICARO is interested in the impact of workload changes on the data center changes like adding move Virtual Machines.
13. **SPECI [Sriram, 2009]** is a discrete event simulation tool for Elastic Cloud Infrastructure that enables exploration of scaling properties of large data centers. The aim of this project is to simulate the performance and behavior of data centers, given the size and middleware design policy as input. SPECI does not provide any support for VMs, load balancing, security and job scheduling.

14. **GroudSim [Ostermann et al., 2010]** is a simulator for both Cloud and Grid Computing environments. It is developed for scientific workflow applications. The developed simulation framework supports modelling of network resources, job submissions, file transfers, as well as integration of failure, background load, and cost models.
15. **SmartSim [Shiraz et al., 2012]** is developed to simulate applications for Mobile Cloud Computing running in Smart Mobile Devices (SMDs). It simulates the behavior of the mobile devices and resources intensive mobile applications. In addition, SmartSim models the mechanism of runtime partitioning of elastic mobile application and determines resources utilization on SMDs during the execution of the elastic application.
16. **SimIC [Sotiriadis et al., 2013]** is aiming to achieving interoperability, flexibility and service elasticity while at the same time introducing the notion of heterogeneity of multiple cloud configurations. It uses Inter-Cloud Meta Scheduling (ICMS) algorithm for inter-cloud scheduling with several distributed parameters.
17. **DynamicCloudSim [Bux and Leser, 2015]** is an extension of CloudSim to simulate instability caused due to heterogeneity of cloud computing, dynamic changes due to several factors at runtime and failures during task execution. Furthermore, DynamicCloudSim introduces a fine-grained representation of computational resources, thereby enabling the simulation of executing different kinds of applications (CPU-, I/O-, communication-bound) on machines with different performance characteristics.
18. **CloudSimSDN [Son et al., 2015]** is based on CloudSim. It is a scalable simulation environment to analyze the network allocation capacity policies like measuring the network performance and host capacity allocation approaches simultaneously within a data center.
19. **secCloudSim [Rehman et al., 2014]** is an extension of iCanCloud simulator which provides security features like authentication and authorization. However, it does not support advanced security mechanisms like privacy, integrity and encryption of VMs.
20. **CEPSim [Higashino et al., 2016]** (Complex Event Processing Simulator) is an extension to CloudSim that allows to simulate cloud applications based on directed acyclic graphs used to represent continuous CEP queries. It includes simulating queries in heterogeneous cloud environments under different load conditions.
21. **PICS [Kim et al., 2015]** (Public IaaS Cloud Simulator) is a simulator to evaluate the cost and performance of public IaaS cloud along dimensions like VM, storage service, resource elasticity,

job scheduling and diverse workload patterns. It does not support heterogeneous cloud deployment feature nor modeling the communication costs.

22. **TeachCloud [Jararweh et al., 2013]** is an extension to CloudSim that helps students to have hands-on experiment with various components involved in Cloud environment such as processing elements, data centers, networking, Service Level Agreement (SLA) constraints, web-based applications, Service Oriented Architecture (SOA), virtualization, management and automation, and Business Process Management (BPM).
23. **CDOSim [Fittkau et al., 2012]** is a simulation tool providing Cloud Deployment Options (CDOs) for Software Migration Support. It identifies the process of analyzing potential CDOs manually is intractable, costly, and time consuming. CDOSim simulates various properties of CDOs such as response times, SLA violations, and costs. CDOSim is integrated with their own Cloud migration framework CloudMIG.
24. **CloudNetSim++ [Malik et al., 2014]** is a simulator for distributed data centers. CloudNetSim++ supports to analyze energy consumption by varying number of nodes and other parameters. In addition to standard network performance measures like delay and throughput for various topologies. It provides a rich GUI, and communication among different nodes which is achieved through packets.
25. **DartCSim+ [Li et al., 2013]** is an enhancement to CloudSim. It integrates power and network models so making network and scheduling algorithms power-aware. In addition, it has a mechanism for controlling transmission of network links is also added which solve the problem of distortion. It hides simulation details and provides friendly GUI for users to conduct their experiments.
26. **GDCSim [Gupta et al., 2014]** is developed to support and handle compute-aware applications such as computational fluid dynamics (CFD). GDCSim supports online resource management and makes prediction of performance and energy consumption for data centers. Having three components, individual component can be used independently or they can be used all together. The simulator can be used for data center infrastructure management, facility performance analysis, workload scheduling or thermal modeling.
27. **FlexCloud [Xu et al., 2015]** is a flexible and scalable simulator that simplifies the scheduling process and enables cloud data centers initializing, VM requests allocation, and performance evaluation for various scheduling algorithms. It offers infrastructure as a Service. It has

advantage over CloudSim in computing time and memory consumption to support large-scale simulations.

28. **VirtualCloud [Das, 2010]** is developed to get efficient usage of virtualized resources (specifically testing policies on real world) in Cloud environment and it is yet useful for modeling and testing new policies.
29. **Cloud²Sim [Kathiravelu and Veiga, 2014]** is an adaptively scaling middleware platform for concurrent and distributed cloud and MapReduce simulations, by leveraging CloudSim. Cloud²Sim proposes a distributed concurrent architecture to CloudSim simulations by using Hazelcast in-memory data grid. In addition, it adopts an adaptive architecture to elastically scale the resources made available to the simulation.
30. **DesktopCloudSim [Alwabel et al., 2015]** as an extension tool CloudSim that enables the simulation of node failures in the infrastructure of Cloud. It demonstrated that the tool can be used to study the throughput of a Desktop Cloud using NotreDame real traces.
31. **WorkflowSim [Chen and Deelman, 2012]** extends the CloudSim simulation toolkit to support workflow preparation and execution. In addition, it includes implementation of a stack of workflow parser, workflow engine and job scheduler. It supports set of workflow scheduling algorithms (e.g., HEFT, Min-Min, and Max-Min) and task clustering algorithms.
32. **CloudMIG [Frey and Hasselbring, 2011]** facilitates the comparison and planning phases for the migration of software systems to PaaS or IaaS-based Cloud environments. Code models can be extracted from Java-based software to (1) model the current system deployment and augment it with a present workload profile, (2) compare the trade-offs that have to be made for different cloud deployment options, and (3) automatically transform the system model to a CloudSim model to enable integrated simulation of various cloud deployment options regarding future costs, response times, and SLA violations.
33. **EduCloud [Cemim et al., 2012]** is a tool to build testbeds using standard hardware and software. EduCloud executes tasks related to the management of a cloud infrastructure, serving as an option to demonstrate the concepts of cloud computing. It also enables the deployment of a private cloud using heterogeneous resources, composed by common hardware usually found in academic environments.

Tables 1, 2, 3, and 4 show evaluation of some of the Cloud Simulators against the functional requirements mentioned in sub-section 4.1. We grouped the requirements based on cloud services related requirements, special aspects related requirements, cloud components modeling requirements, and simulation related requirements.

Table 1. Cloud Simulators Evaluation based on Cloud Services Requirements

Requirement \ Simulator	CloudSim	CloudAnalyst	GreenCloud	iCanCloud	MDCSim	NetworkCloudSim	EMUSIM	CloudReport	CloudSched	CloudExp	DCSim	ICARO	SPECI	GroudSim	SmartSim	SimIC	DynamicCloudSim	CloudSimSDN	SecCloudSim	CEPSim	PICS	TeachCloud	CDOSim	CloudNetSim++	DartCSim+	GDCSim	FlexCloud	VirtualCloud	Cloud²Sim	DesktopCloudSim	WorkflowSim	CloudMIG	EduCloud
Support IaaS	√	√	√	√	×	√	√	√	√	√	√	√	√	√	√	×	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Support PaaS	×	×	×	×	×	×	×	×	×	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×
Support SaaS	×	×	×	HPC	×	×	×	√	×	√	×	×	×	×	×	×	×	×	HPC	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Federation Policy	√	√	×	×	×	√	×	×	×	×	×	×	×	×	√	√	√	√	×	√	×	√	√	√	√	×	×	×	√	×	×	×	×
Modeling of Public Cloud Providers	×	×	×	Amazon EC2	×	×	Amazon EC2	×	Amazon EC2	×	×	×	×	×	×	×	×	×	×	×	Amazon S3	√	√	×	×	×	Amazon EC2	×	×	×	×	×	×
Migration Policy	√	×	×	×	×	√	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	×	×	×	×	×

Table 2. Cloud Simulators Evaluation based on Special Related Requirements

Requirement \ Simulator	CloudSim	CloudAnalyst	GreenCloud	iCanCloud	MDCSim	NetworkCloudSim	EMUSIM	CloudReport	CloudSched	CloudExp	DCSim	ICARO	SPECI	GroudSim	SmartSim	SimIC	DynamicCloudSim	CloudSimSDN	SecCloudSim	CEPSim	PICS	TeachCloud	CDOSim	CloudNetSim++	DartCSim+	GDCSim	FlexCloud	VirtualCloud	Cloud²Sim	DesktopCloudSim	WorkflowSim	CloudMIG	EduCloud
Security	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Mobile Cloud	×	×	×	×	×	×	×	×	×	√	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Desktop Cloud	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	×	×
Quality Metrics	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Problems Solver	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

Table 3. Cloud Simulators Evaluation based on Cloud Components Modeling Requirements

Requirement / Simulator	Cost Modeling	Communication Modeling	Energy Modeling	Power Saving Modes	Physical Modeling	Application Models
CloudSim	√	Limited	√	DVFS	X	Computation & Data Transfer
CloudAnalyst	√	Limited	√	DVFS	X	Computation & Data Transfer
GreenCloud	X	√	Servers & Network	DVFS, DNS, & Both	X	Computation, Data Transfer, & Execution Deadline
iCanCloud	√	√	X	X	√	Computation & Data Transfer
MDCSim	X	Limited	Servers	X	X	Computation
NetworkCloudSim	√	√	√	√	X	Computation, Data Transfer, & Execution Deadline
EMUSIM	√	Limited	√	√	X	Computation & Data Transfer
CloudReport	√	√	Servers & Network	X	√	Computation & Data Transfer
CloudSched	X	√	Servers & Network	√	√	Computation & Data Transfer
CloudExp	√	√	Devices & Network	√	√	Computation & Data Transfer
DCSim	√	X	Hosts	√	X	Computation & Data Transfer
ICARO	X	X	X	X	X	Multi-Tier
SPECI	X	√	X	X	X	Computation & Data Transfer
GroudSim	√	X	X	√	X	Computation & Data Transfer
SmartSim	√	Limited	Devices & Network	√	X	Computation & Data Transfer
SimIC	√	Limited	Servers	X	X	Computation & Data Transfer
DynamicCloudSim	√	√	X	√	X	Computation & Data Transfer
CloudSimSDN	√	√	Servers & Network	√	X	Computation & Data Transfer
SecCloudSim	√	√	X	X	√	Computation & Data Transfer
CEPSim	√	Limited	√	√	X	Computation & Data Transfer
PICS	√	X	X	X	X	Computation, Data Transfer, & Execution Deadline
TeachCloud	√	Limited	√	√	X	Computation & Data Transfer
CDOSim	√	Limited	√	√	X	Computation & Data Transfer
CloudNetSim++	√	Limited	√	√	X	Computation & Data Transfer
DartCSim+	√	Limited	√	√	X	Computation & Data Transfer
GDCSim	X	X	√	√	X	Computation & Data Transfer
FlexCloud	√	Limited	√	√	√	Computation & Data Transfer
VirtualCloud	X	Limited	X	X	√	Computation & Data Transfer
Cloud²Sim	√	Limited	√	√	X	Computation & Data Transfer
DesktopCloudSim	√	Limited	√	√	X	Computation & Data Transfer
WorkflowSim	√	Limited	√	√	X	Computation & Data Transfer
CloudMIG	√	Limited	√	√	X	Computation & Data Transfer
EduCloud	√	Limited	√	√	X	Computation & Data Transfer

DVFS: Dynamic Voltage and Frequency Scaling. DNS: Dynamic Network Shutdown.

Table 4. Cloud Simulators Evaluation based on Simulation Related Requirements

Simulator Type	Parallel Experiments	Simulation Time	Availability	Hardware / Software Companion	Programming Language	Underlying Platform	Experiments Repeatability	Graphical Interface	User Preferences	Dynamic Run	Requirement / Simulator
Event-Based	X	Seconds	√	Software	Java	SimJava	√	X	√	√	CloudSim
Event-Based	X	Seconds	√	Software	Java	CloudSim / SimJava	√	√	√	√	CloudAnalyst
Packet Level	X	Minutes	√	Both	C++ / oTcl	NS2	√	√	X	√	GreenCloud
Event-Based	WiP	Seconds	√	Software	C++	SIMCAN, OMNET, MPI	√	√	√	√	iCanCloud
Event-Based	√	Seconds	X	Software	C++ / Java	CSIM	√	X	√	√	MDCSim
Packet Level	X	Seconds	√	Software	Java	CloudSim	√	X	√	√	NetworkCloudSim
Event-Based	X	Seconds	√	Both	Java	CloudSim & AEF	√	√	√	√	EMUSIM
Event-Based	X	Seconds	X	Software	Java	CloudSim	√	√	√	√	CloudReport
Event-Based	X	Seconds	√	Software	Java	-	√	√	√	√	CloudSched
Event-Based	X	Seconds	X	Software	Java	CloudSim	√	√	√	√	CloudExp
Event-Based	X	Minutes	√	Software	Java	-	√	X	√	√	DCSim
Event-Based	X	Seconds	√	Software	Java	-	√	√	√	√	ICARO
Event-Based	X	Seconds	√	Software	Java	SimKit / Java DES	√	X	√	√	SPECI
Event-Based	X	Seconds	√	Software	Java	-	√	X	√	√	GroudSim
Event-Based	X	Seconds	√	Software	Java	CloudSim	√	X	√	√	SmartSim
Event-Based	X	Seconds	X	Software	Java	SimJava	√	X	√	√	SimIC
Event=Based	X	Seconds	√	Software	Java	CloudSim	√	X	√	√	DynamicCloudSim
Packet Level	X	Seconds	√	Software	Java	CloudSim	√	√	√	√	CloudSimSDN
Event-Based	X	Seconds	X	Software	C++	iCanCloud	√	√	√	√	SecCloudSim
Event-Based	X	Seconds	X	Software	Java	CloudSim	√	√	√	√	CEPSim
Event-Based	X	Minutes	√	Software	Python	-	√	X	√	√	PICS
Event-Based	X	Seconds	√	Software	Java	CloudSim	√	√	√	√	TeachCloud
Event-Based	X	Seconds	X	Software	Java	CloudSim	√	X	√	√	CDOSim
Packet Level	X	Seconds	√	Software	Java	CloudSim	√	√	√	√	CloudNetSim++
Packet Level	X	Seconds	√	Software	Java	CloudSim	√	√	√	√	DartCSim+
Event-Based	X	Seconds	√	Software	C++/XML	Bluetool	√	X	√	√	GDCSim
Event-Based	X	Seconds	√	Software	Java	-	√	√	√	√	FlexCloud
Event-Based	X	Seconds	X	Software	XML	-	√	√	√	√	VirtualCloud
Event-Based	X	Seconds	√	Software	Java	CloudSim	√	X	√	√	Cloud²Sim
Event-Based	X	Seconds	√	Software	Java	CloudSim	√	X	√	√	DesktopCloudSim
Event-Based	X	Seconds	√	Software	Java	CloudSim	√	X	√	√	WorkflowSim
Event-Based	X	Seconds	√	Software	Java	CloudSim	√	X	√	√	CloudMIG
Event-Based	X	Seconds	√	Both	Java	-	√	X	√	√	EduCloud

Discussion

The first step in selecting the Cloud Simulator to model a problem is to decide which of the features required in the Cloud Simulator. Many challenges are facing the Cloud Computing like: security, cost modeling, energy management, and virtual machine migration. Unfortunately, most of the developed simulators were developed to handle one challenge only. That's prevent getting a standard platform for Cloud Simulation. This sub-section details the evaluation discussion based on our study of Cloud Simulators mentioned in Tables 1, 2, 3, and 4. The interesting results are mentioned below with explanations.

From tables 1, 2, 3 and 4 it is observed that:

- All studied simulators support quality metrics (e.g response time, throughput … etc). Each simulator supports a set of quality metrics which may differ from other simulators but they are sharing the implementation of extending the quality metrics with more metrics based on the problem requirements.
- All studied simulators support suggesting optimum configuration of the cloud elements that support the studied environment.
- All studied simulators support dynamic run of the experiments that gives the user the ability to change the elements configuration while the experiment is running.
- All studied simulators support storing user preferences for the experiments parameters so that the user can keep them for future run of the experiment.
- Around 48% of the Cloud Simulators under study have Graphical User Interface (GUI). Researchers prefer simulators with support of the GUI to make it easier to configure and run the experiments.
- All studied simulators support running experiments for several time with the same user preferences so that user can get average of the experiments results.
- Around 52% of the Cloud Simulators are built upon CloudSim simulator. This is give an indication why Java is the most common programming language used for developing Cloud Simulators under study. The second predominant base programming language is C++. Only PICS simulator was developed using Python.
- GreenCloud, EMUSIM, and EduCloud are the only simulators that combines simulation and modeling of the hardware with simulation of the cloud software.

- Around 94% of the simulators support simulating IaaS, while few of them support simulating PaaS and SaaS.
- Around 76% of the Cloud Simulators under study are available under the licenses of open source code for download.
- Around 79% of the Cloud Simulators studied support modeling of the cost. This is important for cloud providers to examine the new pricing plans and strategies.
- Few of the cloud simulators studied don't support getting a communication model in place for interaction of the cloud elements.
- Most of the simulators studied are fast and show the experiments results in tense of seconds.
- Around 63% of the studied simulators support energy modeling by modeling servers, devices, network, or all of connected devices at the same time.
- Around 73% of the studied simulators support power saving modes or event collecting information about devices power consumption.
- Around 39% of the Cloud Simulators studied support federation policy simulator as the need to study multiple clouds connected together.
- Around 21% of the Cloud Simulators studied support modeling of the physical components of the resources like allocation policy of memory, scheduling algorithm of the tasks, latency of I/O… etc.
- Four Cloud Simulators support modeling of Amazon EC2 and one simulator support modeling of Amazon S3.
- iCanCloud is the only Cloud Simulator which has a plan to get the feature of running several independent experiments in parallel to utilize the available resources for the simulator.
- All of the studied simulators support application models through parameterizing computation, data transfer and some of them support execution deadlines.
- All simulators interested in network simulation are based on simulating packets communicated among the cloud elements.
- CloudExp and secCloudSim are the only simulators supporting security features while modeling the interaction between Cloud elements.

- CloudExp and SmartSim are Cloud Simulators supporting modeling of mobile devices connected to the cloud infrastructure to offload data and intensive computations.
- DesktopCloudSim and WorkflowSim are Cloud Simulators supporting modeling of desktop machines connected to the cloud infrastructure to offload data and intensive computations.
- CloudSim, NetworkCloudSim, DCSim, FlexCloud, and VirtualCloud are the only studied simulators studying VM migration policies.

Conclusion and Future Work

Cloud computing is getting computing resources available over a network as a service to end user. It is growing at a much faster rate and faced with many challenges. To carry out a fundamental research in Cloud Computing, Cloud Simulators are considered to be a better option rather than real deployment of cloud. This paper discussed the benefits of cloud simulators along with brief descriptions of 33 Cloud Simulators. The management, load, and test tools are found for Cloud Computing. All the 33 Cloud Simulators have been compared based on 28 evaluation criteria namely: (1) quality metrics, (2) solver for user problems, (3) dynamically run the simulation, (4) preferences, (5) graphical representation, (6) experiments repeatability, (7) underlying platform, (8) programming language, (9) hardware/software companions, (10) support IaaS, (11) support PaaS, (12) support SaaS, (13) federation policy , (14) modeling of public cloud providers , (15) VM migration policy, (16) security, (17) support mobile cloud computing, (18) support desktop cloud computing, (19) cost-modeling, (20) communication modeling, (21) energy modeling, (22) power saving models, (23) physical modeling, (24) application models, (25) availability (open-source), (26) simulation time, (27) parallel experiments, and (28) simulator type (event-based, packet-level). The results and discussion of the evaluation analysis have been presented. Although, there are several Cloud Simulators developed, choosing the best simulator for an experiment or for a proposed resolution of an issue depends up on the type of the problem. None of the introduced tools is the best of all. Each simulator is proposed for a specific application and conditions of cloud environment and the researchers choose the best adapted tool according to their requirements and applications.

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