Simulation Tools for Cloud Computing: A Survey and Comparative Study

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***Abstract*—Today, cloud computing has become a promising paradigm that aims at delivering computing resources and services on demand. The adoption of these services has been rapidly increasing. One of the main issues in this context is how to evaluate the ability of cloud systems to provide the desired services while respecting the QoS constraints. Experimentation in a real environment is a hard problem. In fact, the financial cost and the time required are very high. Also, the experiments are not repeatable, because a number of variables that are not under control of the tester may affect experimental results. Therefore, using simulation frameworks to evaluate cloud applications is preferred. This paper presents a survey of the existing simulation tools in cloud computing. It provides also a critical and comparative analysis of the studied tools. Finally, it stands out a major challenge to be addressed for further research.**

***Keywords*—Cloud computing, simulation tools, comparative analysis**

I. INTRODUCTION

Cloud computing has emerged as a new technology which provides large amounts of computing and data storage capacity to its users. It aims to overcome many problems arising from the rapid evolution of enterprises and the growth of their data. In fact, the accessible space for the storage of information on a personal computer cannot meet the current needs. In addition, maintenance costs of hardware have increased [2].

Currently, cloud environments are making use of virtualization technologies. Instead of running programs on computers, everything is hosted in the cloud. The latter is a model enabling an on-demand network access to a shared pool of configurable computing resources (storage, applications, services, etc.). It offers services that can be classified in three categories [21]: software as a service (SaaS), platform as a service (PaaS) and infrastructure as a service (IaaS). The users can consume these services based on a Service Level Agreement (SLA) which defines their required Quality of Service (QoS) parameters, on a “pay-as-you-go” basis.

In recent years, the number of companies moving into the cloud has increased considerably. Then, it is necessary to evaluate the performance levels of cloud systems. The experimentation in a real environment is not advisable. In fact, the deployment of a cloud system generally requires the use of many hardware resources, network resources, storage resources, etc. In addition, with a real cloud system, the evaluation of some critical scenarios and failure is difficult to achieve Also, repeating experiments is impossible. Moreover, performing experiments with a real cloud system needs to have certain knowledge of networking fundamentals, cloud resource management, cloud security, etc. Furthermore, the financial cost and time required by these experiments are often very high.
Then, a more viable solution to overcome these issues is to use simulation tools that can evaluate the performance of cloud applications before deploying them in a real setup. The simulation technology has become well-known in cloud industry and academy. It offers a free environment that can mimic the behavior of a real cloud environment [4]. In fact, using a simulation approach, experiments can be easily controlled and repeated. Indeed, they need less effort to prepare and test experiment scenarios. Unlike a real environment, experiments using a simulation tool can be replicated quickly and the results can be reproduced easily.

Several simulation tools are available for carrying out research in the cloud [6][11][30][23][27]. Nevertheless, selecting the right simulator to use needs a thorough analysis of the available tools. Previous attempts to survey simulation tools for cloud computing can be seen in the literature [22]. In this survey paper, we strive to offer an updated view of this topic. We give an overview of the existing simulation tools in the cloud. Also, we present a deep comparative analysis of these tools based on different attributes. Furthermore, the paper introduces a new challenge that have to be addressed.

The remainder of this paper is structured as follows. In section II, we give a description of the existing cloud simulation tools. In section III, we present a rich discussion and a comparative study of these simulators based on various criteria. Finally, the last section concludes and highlights an emerging research challenge to address in our future work.

II. OVERVIEW ON THE EXISTING CLOUD SIMULATION TOOLS

In this section, we present a detailed study of cloud simulators proposed in the literature. We begin by presenting the popular simulator CloudSim and its extensions. After that, we introduce the other simulators.

A. CloudSim and its extensions

1) CloudSim: CloudSim [6] is a well-known cloud computing simulator built upon GridSim. It has been developed in the CLOUDS Laboratory at the University of Melborne. It provides a toolkit for modeling and simulating the behavior of many cloud components such as virtual machines (VMs), data centers and resource provisioning services. Also, it can

978-1-5090-5507-4/17/$31.00 ©2017 IEEE
ICIS 2017, May 24-26, 2017, Wuhan, China

represent different types of clouds (public, private, hybrid and multi-cloud environments).
CloudSim is an event-driven simulation tool, that is to say, all components of the simulation maintain a message queue and generate messages, which they pass along to other entities. It can instantiate many data centers which consists of storage servers and physical host machines. These machines host multiple VMs executing several tasks (named cloudlets). CloudSim can perform simulations of assigning and executing a workload on a cloud infrastructure [7]. The communication flow among core CloudSim entities is shown in Figure 1:

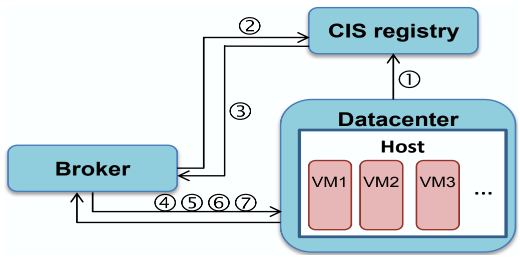

Fig. 1. Flow of communication among CloudSim entities

① At the beginning of a simulation, each data center entity registers its information in the Cloud Information Service (CIS) registry.
② The data center broker (DCB) acting on behalf of users queries the CIS registry for the information of data centers.
③ The CIS registry responds by sending a list of the available data centers.
④ The DCB requests the characteristics of the available data centers (DC).
⑤ The DCB asks the concerned DC to create the required VMs.
⑥ Once the VMs are created, the DCB sends cloudlets to DC for execution. If cloudlets finish their execution, a message is sent to the DCB.
⑦ At the end of the simulation, the VMs will be destroyed.
CloudSim enables modeling and simulation of a large scale infrastructure. In addition, it is easily extensible. In fact, it helps to develop new scheduling algorithms and resource distribution policies.

2) Extensions: Despite its advantages, CloudSim has several limitations. So, many attempts have been made to add to it new functionalities based on different requirements. We cite afterwards some of these extensions.

- **NetworkCloudSim:** It is an extension of CloudSim simulator proposed by Garg et al. [11]. It supports the modeling of generalized applications such as workflows, e-commerce and web applications. Also, it introduces new concepts to model an internal network of a data center. It has two levels of scheduling. The first one is at the host level. It consists in scheduling tasks on VMs. The other is at the VM level where real applications are executed.

- **FederatedCloudSim:** It is a framework which extends CloudSim to simulate several federated cloud scenarios [19]. Moreover, it adds packages for testing SLA-aware scheduling algorithms.

- **DynamicCloudSim:** It is a simulator built on CloudSim. It introduces models to capture inhomogeneity in the performance of computational resources, uncertainty and dynamic changes of VMs performance as well as failure during task execution [3].

- **TeachCloud:** CloudSim lacks a graphical user interface (GUI) which helps the learning process of the students. Thus, a new extension called “TeachCloud” was developed [13]. It serves as an educational toolkit, used by students to conduct experiments in a cloud computing system. It enables building and implementing customized network topologies. Also, it contains new modules related to SLA constraints and business process management (BPM).

- **FTCloudSim:** It introduces new enhancements on top of the CloudSim basic platform to model and simulate the reliability enhancement mechanisms [33]. It provides an extensible interface which helps researchers to implement new mechanisms easily. It adds new modules that can trigger failure events to test the performance of each mechanism. After execution, it generates information that describes the advantages and shortcomings of the mechanism.

- **WorkflowSim:** This toolkit is a new simulator developed by Chen et al [8]. It provides a layer of workflow management in the cloud. This layer introduces support for workflows simulation and scheduling algorithms. It consists of four main components:
  - Workflow mapper: It maps the set of tasks to execution sites;
  - Workflow engine: It handles tasks state and dependencies;
  - Clustering engine: It merges tasks into jobs to reduce the scheduling overhead;
  - Workflow scheduler: It matches jobs to resources;

- **ElasticSim:** It is another extension of CloudSim simulator for workflow applications [5]. It aims to evaluate the performance of scheduling and resource provisioning algorithms. It supports resource runtime auto-scaling and modeling of stochastic task execution time. In addition, it offers a GUI which illustrates the scheduling results. This GUI helps to find the advantages and drawbacks of the proposed algorithms.

- **CloudAnalyst:** It is a simulator based on CloudSim [32]. It aims to evaluate the performance of large-scale distributed applications on cloud. These applications can have high workloads that are geographically distributed over multiple data centers. In addition, CloudAnalyst offers a GUI in order to configure any geographical distributed system such as setting hardware parameters. It generates simulation results in the form of charts and tables.

- **CloudReports:** It introduces many enhancements on top of CloudSim's framework [29]. It provides a GUI which offers many functionalities. Firstly, it allows to run multiple simulations at the same time. Moreover, it can generate reports with detailed information and export simulation data. These information are related to resource usage costs, energy consumption, execution time, etc.

- **CloudExp:** It introduces many enhancements on top of CloudSim basic platform [14]. It provides a user-friendly GUI to enhance the users experience. This GUI can generate and save the results as Excel sheets. It allows to conduct several mobility scenarios for mobile devices. Also, it adds modules related to SLA and some business aspects. In addition, CloudExp integrates new cloud network models that allow to represent current topologies in real cloud environments.
- **MR-CloudSim:** It is an enhanced version of CloudSim that is intended to simulate MapReduce computing Model [15]. It supports BigData processing. However, it does not handle file processing, time and cost related to it. Furthermore, the performance of this tool is not evaluated with a real MapReduce model like Hadoop[1].
- **CloudSimSDN:** It is a cloud simulation tool which supports different SDN features (dynamic network configuration, programmable controller, etc.) [26]. It enables users to evaluate resource management strategies which are applicable to SDN-enabled cloud data centers. In fact, it can simulate data centers, network links, switches, physical machines and virtual topologies in order to measure performance metrics. Moreover, it offers a GUI that simplifies the configuration of simulation.
- **CEPSim:** It is a simulator of cloud-based Complex Event Processing (CEP) systems [12]. It extends CloudSim with an application model based on directed acyclic graphs (DAGs) which is used to represent continuous queries which process fast streams of data. The execution of these queries can be simulated in many types of cloud environment including public, private and multi-cloud environments. Furthermore, this tool can be customized by creating various scheduling strategies and operator placement.
- **CDOSim:** This [10] tool is an extension of CloudSim simulator which can simulate the SLA violations, response times and costs of a CDO (cloud deployment option). It can simulate application models that follow the Knowledge Discovery Meta-Model (KDM). Also, it enables cloud users to compare the cost and efficiency of a cloud solution with those of the other solutions.
- **CloudSimEx:** The major contribution of CloudSimEx [16], is the extension of CloudSim to simulate MapReduce applications. The latter are modeled as a job composed of “map” tasks and “reduce” tasks. Also, it is able to run multiple experiments in parallel, in different JVM processes. CloudSimEx introduces other features related to web-based systems, traffic latency problems, etc.

[1]https://hadoop.apache.org/docs/r1.2.1/mapred_tutorial.html

B. GreenCloud:

It is an open-source tool which is designed for simulating a data center in cloud computing [18]. It is an extension of the well-known simulator in computer networking, NS-2. GreenCloud captures details of the energy consumed by the components of data center (switches, servers and links) as well as packet-level communication patterns in realistic setups. It can also analyze the load distribution through the network.

C. CloudSched:

It is a new simulation tool proposed by Tian et al. [30]. It provides a platform for modeling and evaluating the performance of several scheduling policies in IaaS layer. Besides, it offers graphical and textual outputs after simulation.

D. MDCSim:

It is a discrete event simulator developed at the Pennsylvania State University by Lim et al. [20]. It enables users to model specific hardware characteristics of different components of a data center like servers, communication links and switches. The whole simulation model is configured in three layers: a communication layer, a kernel layer and a user-level layer. The aim is to model and mimic real-world stack from the communication protocols to the applications.

E. iCanCloud:

Nunez et al. [23] have developed the simulation platform ”iCanCloud”. This simulator can predict the trade-offs between cost and performance of a given set of applications executed in a specific hardware. It provides a GUI for designing and running the experiments. Furthermore, it allows parallel execution of one experiment over several machines. Also, it supports simulation of federated cloud environments, that contain internetwork resources from both public and private domains.

F. secCloudSim:

It is built on top of iCanCloud simulator [25]. It provides the basic features of security such as authentication and authorization. The proposed security layer consists of two modules. The first one allows to authenticate users and uses services of cloud in a simulated environment. The second module defines permission sets of rights which differ from one user to another according to their requirement.

G. GroudSim:

It is a simulator developed by Ostermann et al. [24] at the University of Innsbruck. It aims to simulate the execution of scientific applications in a computational grid or cloud. It focuses on IaaS service and it can be extended to support additional models. Moreover, it provides several features for simulating complex scenarios.

H. DCSim:

It is a simulation framework which allows many tenants to simulate virtualized data centers deployed on IaaS cloud [31]. It supports sharing of workload between multiple VMs that are running multi-tier applications. Furthermore, it can evaluate power consumption and SLA violations of data center management system. DCSim can be easily extended to implement new features and functionalities.

I. SimIC:

It is a discrete event simulator based on the SimJava package. It aims to simulate an inter-cloud facility where multiple clouds collaborate [27]. In addition, it supports simulation of heterogeneous and computing environments which are subject to real-time constraints. Furthermore, it can simulate several topologies and entities for IoT (Internet of Things) scenarios.

J. SPECI:

It is a simulation tool which can predict the behavior and performance of large data centers [28]. It also aims to test failure and recovery mechanisms. SPECI is composed of two packages. The first one is devoted to the data center layout and topology. The second one contains simulating components for performing experiments.

K. PICS:

It is a simulation toolkit that aims to evaluate the cost and performance of various public IaaS configurations [17]. In fact, it offers capabilities to evaluate different types of resources, billing models and performance uncertainty. In addition, it can simulate many policies of resources management such as the horizontal and vertical cloud resource scaling, job scheduling policies, etc.

III. Discussion

Throughout this survey paper, we put forward a representative overview of the major efforts of simulation tools available in cloud computing. One of the main problems of researchers is to choose the adequate simulator for their research. In fact, there are cloud simulators which are intended for a specific purpose. Table I presents an attempt to compare the previously described simulators based on different criteria. In the following, we describe the attributes on which we have performed the comparative analysis.

- **Platform:** It represents the underlying platform used to implement the simulator. As illustrated in the table, around 57% of the simulators have been extended from the well known simulator CloudSim.
- **Language:** The languages used to implement the simulators are related to the platforms. Most of the existing simulators use Java language. Others are written in C++. Also, there are some tools which use combinations of languages like GreenCloud and MDCSim.
- **Availability:** This criterion indicates whether a tool is commercial or open source and available to download. We note that 79% of the simulation tools illustrated in the table are open source. The remaining are not available or commercial.
- **Graphical support:** The availability of GUI for simulators helps users to perform the simulations in a simple and efficient way. It allows to define simulation parameters such as the management of VMs. Also, by using a graphical interface, users can execute or cancel simulation and generate graphical or textual reports. As illustrated in the table, the original CloudSim did not support any graphical interface at all. Then, many extensions have been proposed to provide GUI features such as CloudAnalyst and CloudReports.
- **Communication model:** It determines the communication manner between entities of the simulator. For example, GreenCloud has a full communication model. In fact, it implements a full TCP/IP protocol reference model. However, CloudSim has a limited communication model which does not support TCP/IP. The communication between and within data centers takes place by message passing.
- **Energy model:** This criterion tells us whether the simulator allows users to model the energy or not. An energy consumption model aims to compare the efficiency of scheduling algorithms in terms of energy. Some simulators perform only rough estimation on power consumption (like MDCSim).
- **Federation model:** A cloud federation aims to run cloud applications on heterogeneous clouds. The support of federation model means whether a simulator allows users to model federated cloud applications.
- **SLA support:** This criterion determines if the simulator can ensure the requirements stated in the SLA. Based on SLA parameters, requested resources are assigned to users. Some simulators can simulate SLA violations such as DCSim, TeachCloud and GreenCloud.
- **Cost model:** This attribute tells us whether a simulation tool has a module to model costs and determine the price of the used services. Cloud computing adopts pay-as-you-go model where users are charged based on their consumption.
- **Parallel experiments:** The criterion "Parallel experiments" means the ability to combine more than one machine to work together in order to process tasks.

Based on the latest observations, several simulation tools have been proposed in the literature. They aim to model cloud environments and to simulate several workloads running on them. However, they are based on static application models. A significant limitation of these models is the lack of flexibility. From the research directions that have to be considered, we can notice the dynamic adaptation of the simulated applications. In fact, dynamic change has become a major requirement, especially for a long-running application. It helps to cope with unforeseen events and failure that may occur during the execution of an application instance [1]. We cite, for example, the case when the execution time of a task exceeds a

TABLE I. COMPARATIVE STUDY OF CLOUD SIMULATION TOOLS

Tools		Platform	Language	Availability	Graphical support	Communication model	Energy model	Federation model	SLA support	Cost model	Parallel experiments
CloudSim		GridSim	Java	Open source	-	Limited	+	+	-	+	-
CloudSim extensions	**NetworkCloudSim**	CloudSim			-	Full	+	+	-	+	-
	FederatedCloudSim				-	Limited	+	+	-	+	-
	DynamicCloudSim				-	Limited	+	+	-	+	-
	TeachCloud				+	Limited	+	+	+	+	-
	FTCloudSim				-	Limited	+	+	-	+	-
	WorkflowSim				-	Limited	+	+	-	+	-
	ElasticSim				+	Limited	+	+	-	+	-
	CloudAnalyst				+	Limited	+	+	-	+	-
	CloudReports				+	Limited	+	+	-	+	-
	CloudExp			Not available	+	Full	+	+	-	+	-
	DartCSim			Open source	+	Full	+	+	-	+	-
	EMUSIM	CloudSim, AEF			-	Limited	+	-	-	+	-
	MR-CloudSim	CloudSim		Not available	-	Limited	+	+	-	+	-
GreenCloud		NS-2	C++, OTcl	Open source	-	Full	+	-	+	-	-
CloudSched		-	Java	Open source	+	Limited	+	-	-	+	-
MDCSim		CSim	C++, Java	Commercial	-	Limited	Rough	-	-	-	-
iCanCloud		SIMCAN	C++	Open source	+	Full	-	-	-	+	+
secCloudSim		iCanCloud	C++	Not available	-	Full	-	-	-	+	+
GroudSim		-	Java	Open source	-	-	-	-	-	-	-
DCSim		-	Java	Open source	-	-	-	-	+	+	-
SimIC		SimJava	Java	Not available	-	Limited	Rough	+	+	+	-
SPECI		SimKit	Java	Open source	-	-	-	-	-	+	-

certain value, technical problems, etc. Moreover, it can handle new situations to manage the rapid changes demanded by the dynamic nature of the marketplace. Examples of such changes include the change in the customer behavior, the market evolution and the strategy shifts. The changes may be at the functional level (adding tasks, deleting tasks, etc.) or the non functional-level (for example changing time constraint). The need for dynamic change will bring new challenges at the simulation level. So, it is necessary to evaluate provisioning and scheduling policies which can handle the dynamic applications which are simulated.

IV. Conclusion and Research Challenges

To summarize, in this paper we have analyzed and compared the popular cloud simulators in the literature. Based on this analysis and evaluation, we have pointed out the inability of the existing simulators to deal with changes of applications at runtime. Such requirements need a new research contribution.

In our ongoing work, we aim to overcome this limitation of existing simulators. We plan to provide an application model which depicts dynamic changes during execution based on some rules. The change of application model during execution necessarily needs to enhance an existing simulator. We will rely on our previous work [9] which focus on workflows which have become an effective way to the development of scientific applications.

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