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A Comprehensive Assessment and Comparative Analysis of Simulations Tools for Cloud Computing

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Abstract: ***Offering "Computing as a utility" on pay per use plan, Cloud computing has emerged as a technology of ease and flexibility for thousands of users over last few years. In Cloud, computational resources are rented avoiding huge investment on the industry part. Due to this attractive offering, adoption and deployment of Cloud have become very popular not only among industries but also in the research community. But, due to lack of infrastructure and due to problems using the real hardware and software resources because of its high costs and other economical issues, it is not always possible for the research community to work on the actual Cloud for carrying out their experiments and testing & implementing proposals. For fulfilling such requirement, modeling and simulation technologies are required which make them available a look and feel of real Cloud offerings. In this paper, we make an exhaustive assessment and comparative analysis of around twenty simulation tools for Cloud environment.***

Keywords: Cloud computing, Simulation, Simulators, CloudSim , CloudAnalyst, GreenCloud, iCanCloud, MDCSim, NetworkCloudSim, VirtualCloud, SimGrid, GridSim, EMUSim, DCSim, SPECI, Open Cloud Testbed, Open Cirrus, CDOSim, TeachCloud, GroudSim, FlexCloud, GDCSim, MR-CloudSim

1. Introduction

As information and communication technology (ICT) grows gradually, the need for computational resources has also increased than before. Investing in a huge amount of IT assets may not be a good alternative for many industries. The answer to this issue is Cloud computing where computing resources are rented rather than owned. Combining the features of grid, cluster and utility computing mingled with virtualization, Cloud computing offers an innovative model of "computing as a utility" wherein computing resources such as processing elements, memory, storage, bandwidth etc. are provisioned on demand over the Internet on pay per use basis with elasticity and flexibility. [1] The concepts have been so popular over recent years that most of the IT giants including Microsoft, Google, Apple, IBM etc. are not an exception to the list of cloud service providers.

Primitively, Cloud offers five essential characteristics viz. (i) On-demand self-service, (ii) Broad network access, (iii) Resource pooling, (iv) Elasticity and (v) Measured services. Broadly Clouds are available in three service models viz. (i) Infrastructure as a service (IaaS) (ii) Platform as a service (PaaS) and (iii) Software as a service (SaaS). There are four options available as far as deploying a Cloud is concerned viz. (i) private (ii) public (iii) hybrid and (iv) community.

Due to numerous benefits offered by Cloud computing, the research community has attracted to it. But, due to lack of infrastructure, problems using the real hardware and software resources due to its high costs and other economical issues, it is not always possible for the research community to work on the actual Cloud for carrying out their experiments and testing & implementing proposals. Hence, it is utmost important to simulate an environment which works in the same fashion to actual infrastructure and gives various options of testing/implementing ideas and measure various criterion specified by the researcher. For fulfilling such requirement, modeling and simulation technologies are required which make them available a look and feel of real Cloud offerings. In this research work, we intend to study various available simulation toolkits available to work for Cloud environment. We further plan to explore them in terms of features they provide, limitations they impose, platforms they offer, architecture they provide etc.

Rest of the paper is organized as follows. Section 2 depicts an overview of Cloud computing with open issues and research directions in Cloud computing. Section 3 describes the detail study and analysis of various Cloud simulators. Section 4 summarizes the simulators depicted in Section 3 in relative comparison. We conclude our work in Section 5 followed by list of references mentioned in Section 6.

2. Open Issues and Research Directions in Cloud computing

In this section, we explore some open issues and research directions in Cloud computing in the later part of this section. Badger et al. [2] identify open issues in Cloud such as performance, reliability, economical issues, compliance and security. Under the performance category, authors identify latency, off-line data synchronization, scalable programming and data Storage Management as the key issues to address. Network dependence, cloud provider outages and safety-critical processing are considered under the reliability. Economic goals include the risk of business continuity, service agreement evaluation, portability of workloads, interoperability between cloud providers and disaster recovery. Compliance makes inclusion of lack of visibility, physical data location, jurisdiction & regulation and support for forensics. Under security classification, various issues such as the risk of unintended data disclosure, data privacy, system integrity, multi-tenancy, browsers, hardware support for trust, key management are included. Further, under the security and privacy concerns of Cloud, authors of [3][4][5] have identified categories such as Trust, architecture, identity and access management, software isolation, data protection, availability, incident response, application security and encryption and key management. Schubert et al. [6] explore research issues in Cloud such as data management, communication and network, resource description and usage, resource management, multiple tenants, federation (& interoperability, portability), programmability and usability, political & legislative, security and business & cost models. Zhang et al. [7] identify research challenges such as automated service provisioning, virtual machine migration, server consolidation, energy management, traffic management and analysis, data security, software frameworks, storage technologies and data management, novel cloud architectures.

3. Cloud Simulations Tools

Due to enormous reasons, research community working in the domain of Cloud computing faces many problems while employing actual Cloud infrastructure. Few of the reasons include (i) lack of physical infrastructure (ii) difficulty in accessing authentic hardware and software resources (iii) high costs and other socio-economical issues (iv) datacenters situated in the large geographical area etc. Because of these reasons, it is not always possible for researchers to work on the actual Cloud environment for carrying out their experiments and testing & implementing proposals. Hence, quite a significant amount of researchers work in simulated environments. Simulation tools have become nearly inevitable for researchers in almost all facets of engineering. In this section, we discuss various (as many as twenty) simulation tools used in the area of Cloud computing. The purpose of this section is to make the novice Cloud researcher aware pros and cons of various Cloud tools. In next section, we compare all these tools on various criterions to assist the Cloud researcher in selecting a suitable simulator for his/her research.

3.1 CloudSim

CloudSim [8] is one of the most widely accepted and used simulation toolkits among the Cloud researchers. Because of extendibility nature of CloudSim, many other extensions (as mentioned beneath) of CloudSim have been proposed. CloudSim is very popular among the contemporary tools because of many features that it provides. It is an event-driven simulator built upon the core engine of grid simulator GridSim [9]. It helps evaluating the performance of Cloud provisioning policies, application workload models and resource performance models for both single and inter-networked clouds (federation of clouds). Offering seamless modeling and simulation, it supports modeling and creation of a huge data center, unlimited number of virtual machines, and inclusion of brokering policy.

3.2 GridSim

Management of resources and scheduling of applications has been identified as key motivational challenges for development of GridSim [9] in heterogeneous and geographically distributed grid environment. These challenges are further classified as security, resource and policy heterogeneity, fault tolerance, continuously changing resource conditions, and politics. Back in 2002, one of the pioneer authors in the domain of Grid, Cluster and Cloud computing, Rajkumar Buyya proposed object-oriented discrete-event driven Grid simulation toolkit called GridSim to overcome the constraint of carrying out scheduler performance evaluation with varying number of resources and users. GridSim provides modeling and simulation of heterogeneous Grid resources with facilities to compose application tasks, to assign tasks to resources and subsequently the overall tasks management. It also assesses performance and scalability of scheduling policies. Enhancements in network-model and resource-model are identified as future scope.

3.3 CloudAnalyst

Evaluation of requirement for geographically distributed (servers as well as workloads) large-scale Cloud applications is identified as key challenge by the authors of CloudAnalyst [10]. Extending the capabilities of CloudSim [8] with an extra feature of GUI support, CloudAnalyst is claimed to be simulating large-scale Cloud applications under varying deployment configurations with a characteristic to distribute applications among available Cloud infrastructure. The outcomes of experiments are graphical charts and tables which are easy to understand. Through the case study of social networking application, real world scenario has been demonstrated.

3.4 GreenCloud

Built on the top of NS-2, GreenCloud [11] simulator is designed to provide energy-aware environment and workload distribution. Unlike other simulators, it captures energy consumed by individual components of datacenter such as servers, switches, routers/gateways and communication link. It is a packet-level simulator forming communication patterns in real Cloud. Large simulation time and more memory consumption are the major limitations of GreenCloud. Hence, it is constrained limited to small size datacenters. Further, it does not find energy consumption on the basis of storage area network techniques.

3.5 iCanCloud

iCanCloud [12] is design to provide flexibility, scalability, performance, usability, large scale experimentation in Cloud infrastructure. It supports GUI and customized hypervisor (to simulate Amazon instances with the options of uni-core/multi-core systems). The simulator permits addition of adapted MPI library and POSIX based API for simulating new applications. It also allows integrating many new brokering policies.

3.6 MDCSim

Performance, power, lack of infrastructural availability and cost are identified as key motivational factors to design MDCSim [13] which is comprehensive, flexible (able to experiment with different design alternatives) and scalable (able to analyze different data center configurations) simulation platform for multi-tier data centers. The simulator is claimed to be accurate in estimating parameters such as throughput, response time and power consumption. Thermal analysis, reliability measurement and servers' provisioning are considered as factors to be added in future work.

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3.7 NetworkCloudSim

Performance analysis of scheduling/provisioning algorithms is difficult due to the issues of scalability and complexity in virtualized resources. Authors of NetworkCloudSim [14] claim that current Cloud simulators lack support for precise evaluation of scheduling algorithms for scientific applications and modeling of the datacenter's interconnection network resulting into nonrealistic data center solutions or in inaccurate solutions for applications with communicating tasks. NetworkCloudSim has been extended from CloudSim [8] to support a scalable network and generalized application model for better accuracy for scheduling/provisioning policies to optimize performance. Integration of packet level network model has been stated as future work.

3.8 VirtualCloud

Efficient usage of virtualized resources (specifically testing policies on real world) in Cloud environment is considered as major challenge for the development of VirtualCloud [15] that is simple yet useful for modeling and testing new policies.

3.9 SimGrid

Recognizing application scheduling as a key issue to address, SimGrid [16] is a simulation tool for application scheduling in distributed, dynamic and heterogeneous environments. SimGrid is claimed to be providing required abstraction & modeling, more realistic simulation, correct & accurate results. Task duplication and complex query-handling are stated as future work.

3.10EMUSim

How the CPU intensive services provided by SaaS will behave in virtualized resources and how the cost of service changes along with the change in the resource requirements; are identified as the key challenges by the authors of EMUSim [17]. Based on an open source software stack, it works in the direction of predicting service's behavior by providing hybrid architecture combining on both emulation (built on Automated Emulation Framework (AEF) [18]) and simulation (built on CloudSim [8]). During emulation, an application is submitted for execution with changeable requests and resources. In simulation phase, application is modeled with the help of profiling information of the actual application collected during emulation.

3.11 DCSim

DCSim - Data Centre Simulation Tool [19] is an extensible framework that addresses the issue of dynamic management of virtualized resources in IaaS Cloud. (Large) size and complexity of dataset restrict algorithms to be feasible on realistic datacenters. DCSim claims to address issues such as customized & extensible simulation toolkit, work conserving CPU scheduler, resource allocation, VM migration and replication. Unlike CloudSim[8], DCSim focuses on transactional, continuous workloads. DCSim computes few metrics such as SLA violation, data centre utilization, active hosts, host-hours, active host utilization, number of migrations and power consumption. Authors recommend adding a data centre networking model to make more intelligent decisions for VM placement and to consider bandwidth constraints on concurrent VM migrations. Additionally, distributed management, consideration of heat generated by physical machine while placing VMs, and failure of physical machine are suggested as the scope for future work.

3.12 SPECI

Simulation Program for Elastic Cloud Infrastructures (SPECI) [20] explores the performance and scaling properties of Datacenters (DCs). Back in 2009, authors identified the issue of prediction of performance & behavior for DCs taking into considerations the size and middleware design policy. They further explore the significance of hardware (server) failure in DCs and impart the significance of resilience mechanism which affects the performance assessment. With experimentations, authors conclude that with increase in the size and failure rate of the DC, management of a distributed DC becomes favorable.

3.13Open Cloud Testbed

Open Cloud Testbed (OCT) [21] is a wide-area Cloud testbed consists of 6 sites with various numbers of nodes, ranging between 128 and 480 per site in four data centers. OCT has been designed and implemented to benchmark the performance of the data intensive computing systems. Further, OCT is used to investigate their interoperability and to experiment with new services based on flexible compute node and network provisioning capabilities. Several utilities have been developed such as novel node, network provisioning services, a monitoring system, and a RPC system. Limitation of OCT is that it is not designed to support computations that span more than one data center (i.e. it is designed for systems that run within a single data center).

3.14Open Cirrus

Open-Cirrus [22] associates distributed data centers to encourage innovation in systems & applications research and inspires development of an open source service stack for the Cloud. Open-Cirrus aims to address the issue of obtaining low-level resource access by providing a single testbed of heterogeneous distributed data centers. Offering collection of experimental dataset, Open-Cirrus intends to cultivate systems-level & application-level research and to develop open source stacks and APIs for cloud. The Open-Cirrus sites (composed of 10 sites in North America, Europe, and Asia) are working together to provide a single federated testbed, as opposed to each site building and operating a separate cluster.

3.15CDOSim

CDOSim [23] is Simulation toolkit providing Cloud Deployment Options (CDOs) for Software Migration Support. Authors identify 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 built on the top of CloudSim [8]. CDOSim is integrated with their own Cloud migration framework CloudMIG. CDOSim monitors actual workload.

3.16 TeachCloud

Authors of TeachCloud [24] claim that there is a lack of a teaching tool to experiment with Cloud. Extension of CloudSim [8], TeachCloud is a modeling and simulation environment useful to the 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). Authors identified few limitations and shortcomings in CloudSim such as lack of GUI, support for simplified network model and a limited workload generator, lack of BPM and SLA components. Authors claim to address these limitations in the TeachCloud simulation toolkit.

3.17GroudSim

As name suggests, GroudSim [25] is a combination of Grid and Cloud simulation toolkit for scientific applications based on scalable core. It provides facility to compute cost and background load. Normal scenario of failures can be easily parameterized and simulated using GroudSim. It is one of the few simulation frameworks available for the scientific research integrating Grid and Cloud. Unlike CloudSim [8] and GridSim [9], which are process-based simulators creating one thread per event, GroudSim is an event-based simulator that creates only one thread per simulation, resulting into more scalable environment.

3.18FlexCloud

FlexCloud [26] 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. Offering Infrastructure as a Service, FlexCloud guarantees flexibility and extendibility in terms of adding new scheduling algorithms. It has advantage over CloudSim in computing time and memory consumption to support large-scale simulations.

3.19 GDCSim

Green Data Center Simulator (GDCSim) [27] has been 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.

3.20MR-CloudSim

Extending the CloudSim framework, authors alters few of the core classes to include modeling and simulation of MapReduce applications. This simulator allows large parallel data (BigData) processing task. MR-CloudSim [28] adds some more features such as file processing, associated cost and time, which are not available in CloudSim.

4. Comparative Analysis

In previous sections, we have analysed and discussed various simulation toolkits used in Cloud computing experimentation. We listed the challenges & motivations identified by the authors of the simulators along with the strength and weaknesses of the tools. In this section, we wish to summarize the toolkits on some commonly known parameters such as underlying platform, available as (open source or commercial), programming language (Java/C/C++), models (cost, energy, communication, security), federation policy, limitations, GUI support, migration policy etc. Table 1 summarizes the simulation tools discussed in the previous section.

5. Conclusion

Cloud computing is one of the most emerging technologies in last decade for Information & Communication Technology sector. Certain issues such as lack of physical infrastructure, high cost, distributed in large geographically area etc. restrict the researchers using the real Cloud deployment and compel them to use simulation environment. This paper discusses various Cloud simulators being used by the research community. The discussion includes the significance of simulators, their comparisons, pros and cons, challenges & motivational factors identified by the simulators and their strengths and limitations. To the best of our understanding, this paper is one of the few papers which make such an exhaustive (as many as twenty) study of Cloud simulators. The paper emphasizes adding the information which is useful for the novice researchers for selecting appropriate simulation tool(s) to match his/her requirements. We have also summarized the comparison of these simulation toolkits in a comprehensive tabular format. Though the selection of simulator depends on individual researcher's needs, we recommend CloudSim as compared to others because of the functions and facilities provided by it.

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Table 1. Comparison Analysis of Various Simulation Toolkits for Cloud Environments

Simulator	Pub. Year	Cited By (as in Oct-2016)	Underlying Platform	Available As	Programming Language	Model				Federation Policy	Graphical Support	Migration Policy
						Cost	Energy	Comm.	Security			
CloudSim	2011	1890	Any	Open Source	JAVA	Yes	Yes	Limited	No	Yes	No	Yes
GridSim	2002	1704	SimJava2	Open Source	JAVA	Yes	No	No	No	No	No	No
CloudAnalyst	2010	312	CloudSim	Open Source	JAVA	Yes	Yes	Limited	No	Yes	Yes	No
GreenCloud	2012	397	NS-2	Open Source	C++, OTcl	No	Yes	Full	No	No	Limited	No
iCanCloud	2012	121	OMNET, MPI	Open Source	C++	Yes	No	Full	No	No	Yes	No
MDCSim	2009	118	CSIM	Commercial	JAVA/C++	No	Rough	Limited	No	No	No	No
NetworkCloudSim	2011	152	CloudSim	Open Source	JAVA	Yes	Yes	Full	No	Yes	No	May
VirtualCloud	2010	3	NA	NA	XML	NA	NA	Limited	No	No	No	Yes
SimGrid	2001	478	NA	Open Source	C or JAVA	Yes	No	No	No	No	No	No
EMUSim	2013	73	CloudSim, AEF	Open Source	JAVA	Yes	Yes	Limited	No	No	No	No
DCSim	2013	7	-	Open Source	JAVA	Yes	No	No	No	No	No	Yes
SPECI	2009	52	SimKit	Open Source	JAVA	No	Rough	Limited	May	No	No	No
Open Cloud Testbed	2009	21	NA	Limited	-	NA	NA	NA	No	NA	NA	No
Open Cirrus	2010	146	NA	Open Source	-	NA	NA	NA	May	NA	No	No
CDOSim	2012	43	CloudSim	-	JAVA	NA	NA	NA	No	NA	No	No
TeachCloud	2013	45	CloudSim	Open Source	JAVA	NA	NA	NA	May	NA	Yes	No
GroudSim	2010	68	-	Open Source	JAVA	No	No	No	No	No	Limited	No
FlexCloud	2015	5	Any	Open Source	JAVA	Yes	Yes	NA	No	NA	Yes	Yes
GDCSim	2014	9	Bluetool	Open Source	C++/XML	NA	Yes	NA	No	NA	No	No
MR-CloudSim	2012	18	CloudSim	NA	JAVA	Yes	Yes	Limited	No	Yes	No	No

(NA- Information Not Available to the best of our understanding)

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