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A Comparative Analysis of Cloud Simulators

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***Abstract*—**Cloud Computing is a new paradigm which allows individuals and organizations to purchase resources like compute, storage, networking etc as a utility with minimum human intervention. According to recent surveys more than half of the large to medium size organizations have already migrated to the cloud. Despite of providing resources as a utility and its wide spread acceptance in the IT community, cloud computing is still at its prime and poses many challenges like automated service provisioning, virtual machine migration, server consolidation, energy management, traffic analysis, data security, software frameworks which needs considerable amount of research to stabilize. Conducting research on live cloud environments for individuals or small institutions is very difficult due to the costs involved in setting up a cloud. This paper presents various cloud simulators which were developed over the years that are a cost effective way of conducting cloud research tasks. This paper compares almost 17 cloud simulators based on diverse criteria and the result and explanations are presented which enables new researchers to choose a suitable cloud simulator.

***Index Terms*—**Cloud computing, cloud simulators, virtual machine, data center.

I. INTRODUCTION

Although cloud computing's inception spans over a decade, still there are many challenging issues which requires a significant amount of research to be done. It is impractical for medium to small sized educational institutions and other organizations to establish a physical cloud for conducting research on cloud computing. It is not possible to perform benchmarking experiments in repeatable, dependable, and scalable environments using real-world cloud environments. A solution for this is to use simulators which can simulate a real cloud environment.

A cloud simulator helps to model various kinds of cloud applications by creating data centers, virtual machines and other utilities that can be configured appropriately, thus making it easier to analyze. To date many cloud simulators had been developed and are being actively used to conduct cloud research. These simulators varies in features like availability of GUI, licensing, base programming language, extensibility etc. In literature [1][2][3][4][5][6][7][8] there are several research papers which already studied various cloud simulation tools. In this paper I present a comprehensive study of various cloud simulators by highlighting their features and analyzing their pros and cons. A table containing comparative analysis of various cloud simulators is available in section 4.

Benefits provided by simulators [4] over establishing a physical cloud are as follows:

- *Minimal Cost*: Purchasing software costs less when compared to purchasing hardware and proprietary software (operating systems, hypervisor etc). Also many simulators are available free of cost.
- *Repeatable and Controllable*: We can test our experimental set up (simulation) as many times as we want until we get the desirable output.
- *Environment*: A simulator provides environment for evaluation of various scenarios under different workloads.

Rest of the information in this paper has been organized as follows: section II gives a overview of various cloud simulators. Section III presents various criteria that were used to perform a comparative analysis of cloud simulators. Section IV gives the results and explanations of the comparative analysis and finally section V concludes with the suggestion of the best simulator for conducting cloud research tasks.

II. CLOUD SIMULATORS

In this section we will look at various cloud simulators that are being widely used to conduct cloud research simulations. Around 17 cloud simulators had been described in this section. Result of comparative analysis of cloud simulators is available in Table 1.

CloudSim

CloudSim [9][24] is the most popular simulation tool available for cloud computing environment. It is an event driven simulator built up on the core of grid simulator GridSim [10]. Base programming language for CloudSim is Java which is one of the famous object oriented programming languages. CloudSim modules are easy to extend as it is based on Java. CloudSim is open source and is free to extend. One unique feature of CloudSim is the federated policy, which is rarely available in any other simulators. CloudSim contains the following features:

- Support modeling and simulation of large scale computing environment.
- A self contained platform for modeling clouds, service brokers, provisioning and allocation policies.
- Support for simulation of network connections among the simulated system elements.
- Facility for simulation of federated cloud environment, that contains inter-network resources from both private and public domains.
- Availability of a virtualization engine that aids in the creation and management of multiple independent and co-hosted virtual services on a data center node.
- Flexibility to switch between space shared and time shared allocation of processing cores to virtualized services.

Architecture of CloudSim [24] is as shown in following figure Fig. 1:

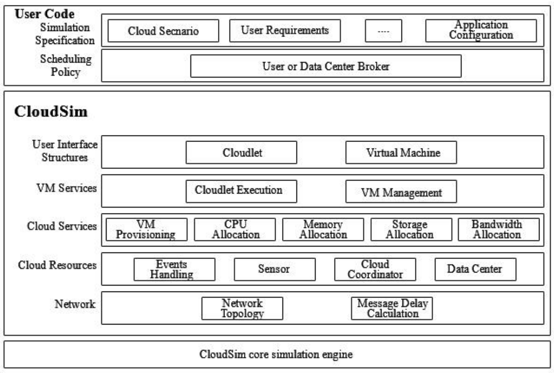

Fig.1. Architecture of CloudSim

Despite many features of CloudSim, one major drawback is the lack of Graphical User Interface (GUI). According to R. Kanniga Devi et al. [6] CloudSim is the frequently used (nearly 23 experiments and may be more) simulation tool for cloud research.

CloudAnalyst

Wickremasinghe et al. [9][25] developed a new simulator called CloudAnalyst which is based up on CloudSim. CloudAnalyst was basically developed for evaluating the performance of large-scale distributed cloud applications having high user workload that are geographically distributed over several data centers. Features of CloudAnalyst are the following:

- Easy to use Graphical User Interface (GUI).
- Ability to define a simulation with a high degree of configurability and flexibility.
- Being able to repeat the experiments with slight modifications.
- Generate graphical output in the form of charts and tables.
- Use of consolidated technology and ease of extension.

Architecture [25] of CloudAnalyst is as shown in following figure Fig. 2.

CloudAnalyst provides an easy to use GUI to configure any geographically distributed system [11], such as description of application workloads, including information of geographic location of users generating traffic and location of data centers, number of users per data center and number of resources in each data center. CloudAnalyst can generate output in the form of chart or table that summarizes the huge amount of users and system statistics during the simulation time.

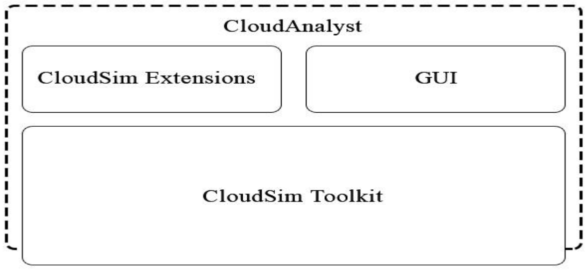

Fig. 2.Architecture of CloudAnalyst

By using CloudAnalyst cloud application developers will be able to determine the best strategy for allocation of resources among data centers and selecting the optimal data center to serve specific requests and minimize costs associated with such requests.

GreenCloud

GreenCloud is a packet level simulator [12][26] developed by extending network simulator NS2 [13], and is specially made for energy-aware environment. GreenCloud is designed so that it can calculate energy consumption at any particular data center components such as link, switch, gateway etc. as well as communication between the packet levels. Further, it offers to know the workload distribution in the system. Key features of GreenCloud are:

- Focus on cloud networking and energy awareness
- Simulation of CPU, memory, storage and networking resources
- Independent energy models for each type of resource
- Suport of virtualization and VM migration
- Network-aware resource allocation
- Complete TCP/IP implementation
- User friendly GUI
- Open Source

Architecture of GreenCloud [26] is as shown in following figure Fig. 3.

One of the drawbacks of GreenCloud is that it takes minutes of time for simulating a model and also consumes huge memory. As it takes more time for simulation, its scalability is restricted to small data center. Another possible drawback is the researcher should learn both C++ language and OTcl libraries to work with

GreenCloud. This simulator is only suitable for work related to calculating energy consumption in data centers (cloud).

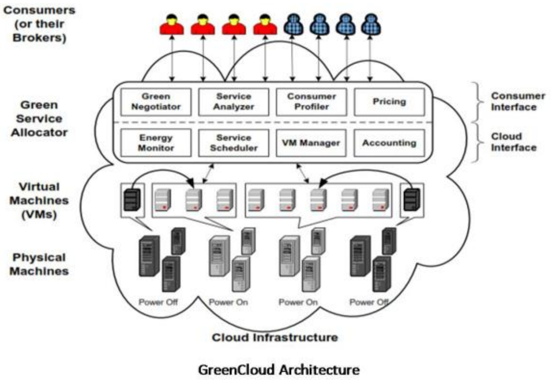

Fig.3. Architecture of GreenCloud

iCanCloud

iCanCloud [14][27] is developed by considering the drawbacks of previous mentioned simulators like CloudSim and GreenCloud. This simulator was developed based on SIMCAN [15]. The unique feature of iCanCloud is that the user can customize the core hypervisor class. Base programming language used for iCanCloud is C++. Key features of iCanCloud simulator are:

- Both existing and non-existing cloud computing architectures can be modeled and simulated.
- A flexible cloud hypervisor module provides an easy method for integrating and testing both new and existent cloud brokering policies.
- iCanCloud provides methods for obtaining the energy consumption of each hardware component in cloud computing systems.
- Users are able to design and model resource provisioning policies for cloud systems to balance the trade-offs between performance and energy consumption.
- Customizable VMs can be used to quickly simulate uni-core/multi-core systems.
- iCanCloud provides a wide range of configurations for storage systems.
- iCanCloud provides a user-friendly GUI to ease the generation and customization of large distributed models.
- iCanCloud provides a POSIX-based API and an adapted MPI library for modelling and simulating applications.
- New components can be added to the repository of iCanCloud to increase the functionality of the simulation platform.

Architecture of iCanCloud is as shown in following figure Fig. 4.

iCanCloud provides a scalable, flexible, fast and easy-to-use tool, which let users, obtain results quickly in order to help to take a decision for paying a corresponding budget of machines.

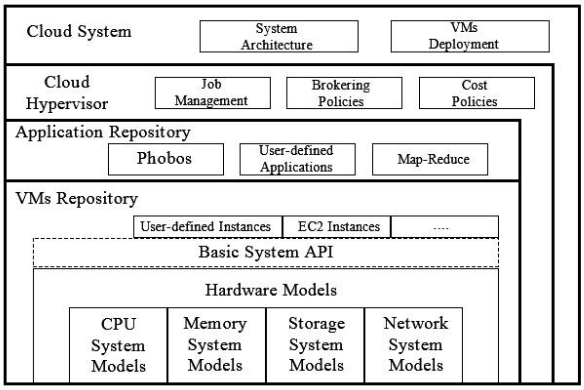

Fig.4. Architecture of iCanCloud

NetworkCloudSim

NetworkCloudSim [16] was proposed by Saurabh Kumar et al. [28] which is an extension of CloudSim. CloudSim and GreenCloud are basically built for single server architecture and becomes insufficient for real cloud model which involves deploying different types of applications from different customers. NetworkCloudSim supports communication between application elements and various network elements.

Architecture of NetworkCloudSim [28] is as shown in following figure Fig. 5:

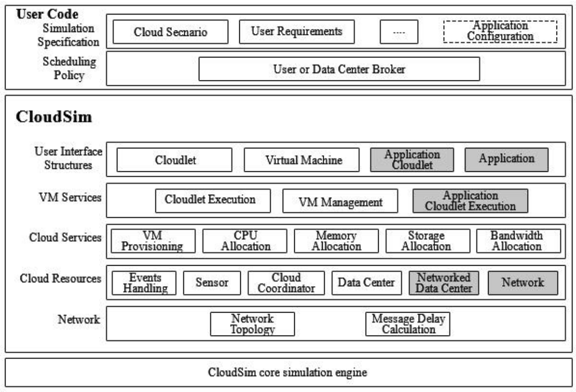

Fig.5. Architecture of NetworkCloudSim

NetworkCloudSim simulator supports more realistic and complex applications with communicating tasks such as parallel & data-driven applications and workflows.

EMUSIM

EMUSIM [17][29] is not only a simulator; it provides both the capabilities of an emulator as well as simulator of a cloud environment. It is developed for CPU intensive SaaS applications which are very costly for actual deployment. For these types of applications customer has to analyze the behavior of the application before subscribing for a cloud plan. EMUSIM is built up on CloudSim and Automated Emulation Framework (AEF).

Architecture of EMUSIM [29] is as shown in following figure Fig. 6:

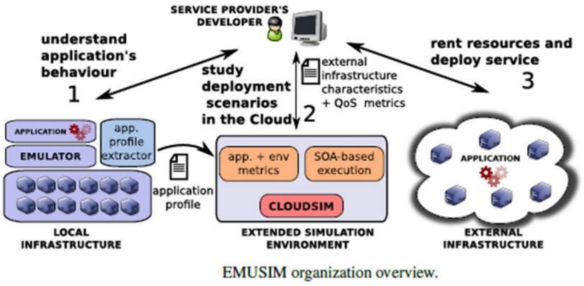

Fig.6. Overview of EMUSIM

EMUSIM, automatically extracts information from application behavior via emulation and then uses this information to generate the corresponding simulation model.

GroudSim

GroudSim [18][30] (Gr-Grid and oud-Cloud Simulator) is a discrete event simulation platform for both cloud and grid computing environments. It is specifically developed for simulating scientific applications in grid and cloud environments. Base programming language for GroudSim is Java. GroudSim can be extended very easily by adopting probability distribution packages. One unique feature is that, GroundEntity in the GroudSim has its own definition for error behaviors, user can change this configuration during each error occurrence. Core components of GroudSim [18] are as shown in following figure Fig. 7:

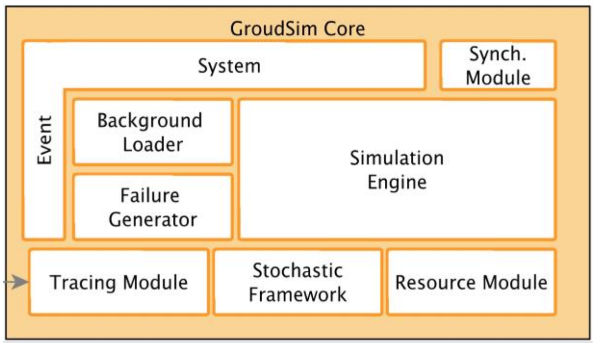

Fig.7. Overview of GroudSim Core

DCSim

DCSim [19][31] simulator was developed to simulate a virtual data center in IaaS model. The data center contains multiple interconnected hosts and each host having its own CPU scheduler and resource management policy. It also supports VM migration among the hosts and sharing of workload between multiple VMs. DCSim simulates data center with centralized management system and neglects data center network topology for higher scalability. Architecture of DCSim [31] is as shown in following figure Fig. 8.

DCSim provides the additional capability of modelling replicated VMs sharing incoming workload as well as dependencies between VMs that are part of a multi-tiered application. SLA achievement can also be more directly and easily measured and available to management elements within the simulation.

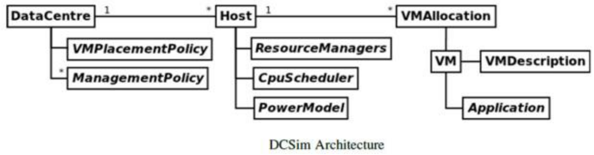

Fig.8. Architecture of DCSim

MR-CloudSim

MR-CloudSim [20] was developed based on CloudSim simulator. The unique feature of MR-CloudSim is its support for simulating MapReduce tasks and there by supporting BigData processing. CloudSim simulator does not support file processing, cost and time associated with it. In MR-CloudSim, authors changed some of the core classes in CloudSim to support MapReduce programming model.

SmartSim

SmartSim [21] is uniquely built for simulating applications for mobile cloud computing. SmartSim is the first ever simulator built that supports mobile cloud applications. Its main feature is to model mobile cloud application running in mobile devices. SmartSim supports both the system and behavior modeling of Smart Mobile Device (SMD) components such as application processor, memory, resources provision, computing resources utilization evaluation, dynamic processing management policies and computational intensive mobile application modeling for SMD. Architecture of SmartSim [21] is as shown in following figure Fig. 9:

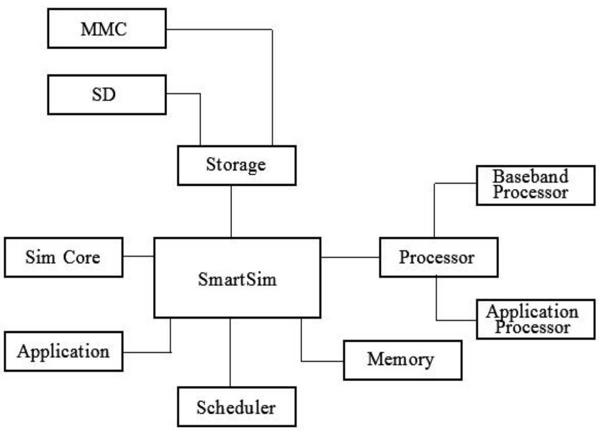

Fig.9. Architecture of SmartSim

SimIC

SimIC [22][32] is a discrete event simulator built up on the SimJava Package. Recent research is geared towards federated clouds, thus exchanging many services between different cloud data centers and eventually increasing quality of service. None of the above mentioned simulators can simulate inter-cloud activities effectively.

The SimIC aims of achieving interoperability, flexibility and service elasticity while at the same time introducing the notion of heterogeneity of multiple cloud configurations. SimIC uses Inter-Cloud Meta Scheduling (ICMS) algorithm for inter-cloud scheduling which depends on several distributed parameters.

SPECI

SPECI [23][33] (Simulation Program for Elastic Cloud Infrastructures) is a discrete event simulation tool that enables exploration of scaling properties of large data centers. The aim of this project is to simulate the performance and behaviour of data centers, given the size and middleware design policy as input. SPECI is built with SimKit which in turn is developed in Java. SPECI does not provide any support for VMs, load balancing, security and job scheduling.

DynamicCloudSim

DynamicCloudSim [35][36] is an extension of CloudSim which is able to simulate instability caused due to heterogeneous nature of cloud computing, dynamic changes due to several factors at runtime and failures during task execution.

Drawbacks of DynamicCloudSim are it considers only one task at a time and data locality issues have not been addressed. Also failure model is limited in this simulator.

CloudSimSDN

CloudSimSDN [37][38] based on CloudSim is a lightweight and scalable simulation environment to analyse the network allocation capacity policies like measuring the network performance and host capacity allocation approaches simultaneously within a data center. Architecture [38] of CloudSimSDN is as shown in following figure Fig. 10:

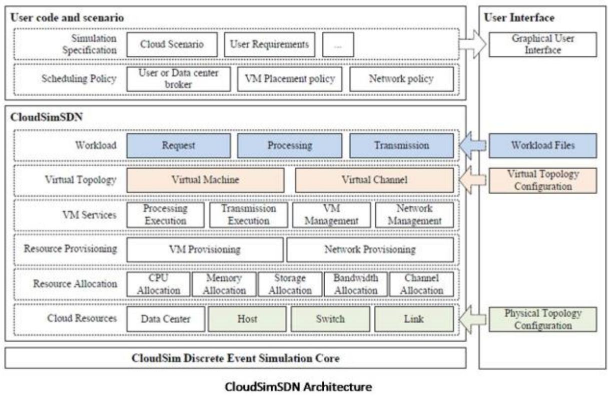

Fig.10. Architecture of SmartSim

secCloudSim

secCloudSim [39] is an extension of iCanCloud simulator which provides security features like authentication and authorization which are not addressed by any of the existing simulators. Architecture [39] of secCloudSim is as shown in following figure Fig. 11:

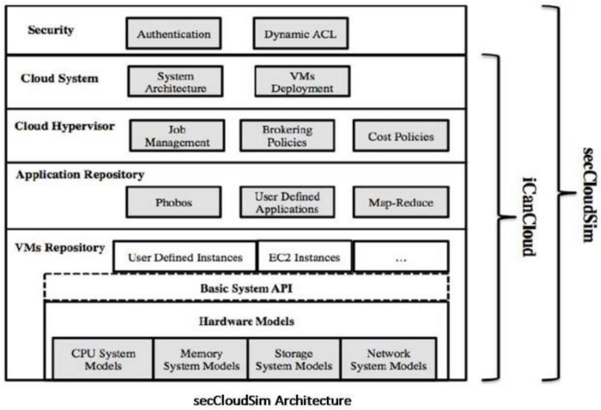

Fig.11. Architecture of secCloudSim

Only drawback of secCloudSim when compared to iCanCloud simulator is that secCloudSim incurs performance lag as it adds extra layer of security functionality to the existing framework. Advanced security mechanisms like privacy, integrity and encryption of VMs are not supported.

CEPSim

CEPSim [40] (Complex Event Processing Simulator) is an extension of CloudSim that allows researchers to work with cloud applications that are modeled based on directed acyclic graphs used to represent continuous CEP queries. A key feature of CEPSim is it allows researchers to simulate queries in heterogeneous cloud environments under different load conditions. One drawback of this simulator is dynamic query analysis is not supported.

PICS

PICS [41][42] (Public IaaS Cloud Simulator) is a simulator designed from cloud user perspective to evaluate the cost and performance of public IaaS cloud along dimensions like VM, storage service, resource elasticity, job scheduling and diverse workload patterns. Overview [42] of PICS is as shown in figure Fig. 12:

Drawbacks of PICS are there is no support for heterogeneous cloud deployment feature and no support to model the communication costs.

III. Evaluation Criteria

In the previous section several cloud simulators were introduced, their features and architecture have been discussed briefly. Main problem for researchers is to choose the correct simulator for their cloud research as there are cloud simulators for specific purpose like SimIC for inter-cloud, SmartSim for mobile cloud computing, MR-CloudSim for MapReduce programming etc. In this section I will introduce several attributes based on which I had performed comparative analysis of the cloud simulators. The criteria for comparison are chosen based on the previous work of several researchers [3][4][7][34] and are as follows:

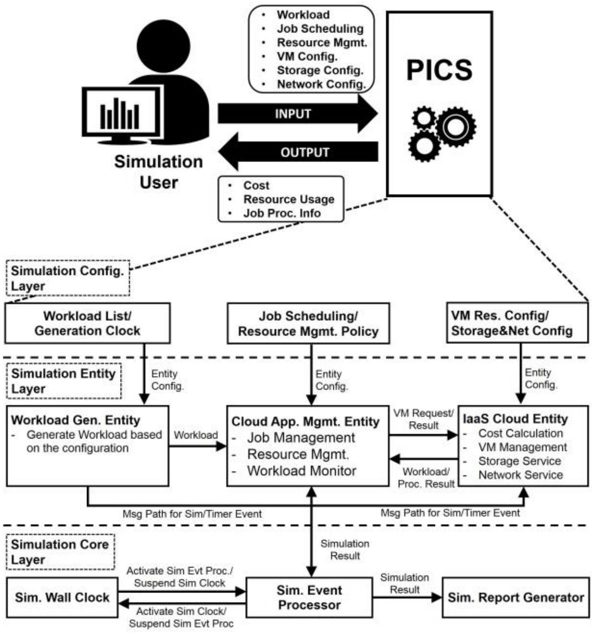

Fig.12. Overview of PICS

Base Platform: Most of the simulators have been developed based on existing simulation framework(s). All the features of the base platform/framework are incorporated in to the new simulation application.

Availability: We should know that cloud simulators are either commercial or open source. This parameter specifies whether the simulator is commercial or free to download and use as in open source. Some simulators are open source but are not available for download.

Programming Language: Most of the cloud research requires modification of the underlying framework or features of the simulator which have been developed using a particular programming language. So it is important to know in which programming language a simulator has been developed.

Cost Modeling: Main characteristic of cloud computing is the provisioning of computing power as a utility which is also termed as pay-per-use model. This attribute informs us whether the simulator contains a module to model costs or include our own policy to determine the price of the service usage or not.

Graphical User Interface (GUI): The availability of GUI for simulator aids the researches to perform their simulations in a simple and efficient way. This attribute tells us whether a simulator provides a GUI or not.

Communication Model: Some of the cloud research is concerned with the costs involved in the data center communication i.e time required for the packets or messages to reach from source equipment or process to destination equipment or process. This attribute tells us whether the simulator supports communication module or not.

Simulation Time: This attribute tells us how long a simulator takes to perform the simulation and present the required results. More simulation time depicts that the simulator is inefficient.

Energy Modeling: Current research trend in cloud computing is concerned with energy aware computing i.e., reducing the power consumption and reducing the heat produced in the data centers. This attribute tells us whether the simulator allows researchers to model the energy or not.

Federation Policy: Another research trend in cloud computing is cloud federation where cloud applications can run on heterogeneous clouds in different administrative domains. This attribute tells us whether a simulator allows researchers to model federated cloud applications or not.

IV. Results & Discussion

This section presents the details of comparative evaluation of different cloud simulators based on the evaluation criteria mentioned in the previous section. The main results along with explanations are given below and the summary of the evaluation is presented in Table 1.

Form the table it is observed that around 47% of the simulators (CloudAnalyst, NetworkCloudSim, EMUSIM, MR-CloudSim, SmartSim, Dynamic CloudSim, CloudSimSDN and CEPSim) have been extended from CloudSim and the only simulators that were built from scratch are GroudSim, DCSim amd PICS. 82% of simulators (except MR-CloudSim, secCloudSim, CEPSim) are open source and are available for download.

It is observed that for most of the simulators (76%) the base programming language used was Java. The second predominant base programming language is C++. Only PICS simulator was developed using Python.

82% of the simulators allows cost modeling. One negative observation is that only 41% of the simulators provide full to limited GUI for researches. Availability of GUI attracts more number of researchers to use the simulator. At least the most popular simulator CloudSim should have a GUI.

Around 82% of the simulators perform the simulation in seconds. The only simulators that does the simulation in minutes are GreenCloud and DCSim. 82% of the simulators support modeling communications in a data center, 70% of the simulators support energy modeling and only 52% of the simulators provide federated cloud support.

Finally, it is worth to mention about some of the special purpose cloud simulators. EMUSIM is the only simulator which allows researchers to evaluate the performance of cloud applications on real hardware.

EMUSIM and PICS are the only simulators that allow researchers to evaluate the performance of cloud application from cloud user perspective. SmartSim is the only cloud simulator that supports Mobile Cloud Computing (MCC). secCloudSim is the only simulator that addresses security related aspects and CloudSimSDN is the only simulator that allows research on cloud architectures with support for SDN (Software Defined Networking).

V. Conclusion

This paper discussed the benefits of cloud simulators over using real cloud environment along with brief descriptions of 17 cloud simulators. The novel work done in this paper is, consideration of latest cloud simulators like DynamicCloudSim, CloudSimSDN, secCloudSim, CEPSim and PICS. All the 17 cloud simulators have been compared based on 9 evaluation criteria namely: base platform, availability, programming language, cost model, GUI, communication model, simulation time, energy model and federation model. The results and explanation of the comparative analysis have been presented.

Although there are several cloud simulators available, I can say that choosing a simulator depends up on the type of problem as there are several simulators geared for certain types of research problems. As a general purpose simulator CloudSim is recommended based on its features and popularity in the research community.

Table 1. Comparative Analysis of Cloud Simulators

Simulator	Base Platform	Availability	Prog. Language	Cost Model	GUI	Comm. Model	Simulation Time	Energy Model	Federation Model
CloudSim	SimJava	Open Source	Java	Yes	No	Limited	Seconds	Yes	Yes
CloudAnalyst	CloudSim	Open Source	Java	Yes	Yes	Limited	Seconds	Yes	Yes
GreenCloud	NS2	Open Source	C++, OTcl	No	Limited	Full	Minutes	Yes	No
iCanCloud	SIMCAN	Open Source	C++	Yes	Yes	Full	Seconds	No	No
Network CloudSim	CloudSim	Open Source	Java	Yes	No	Full	Seconds	Yes	Yes
EMUSIM	CloudSim, AEF	Open Source	Java	Yes	No	Limited	Seconds	Yes	No
GroudSim	-	Open Source	Java	No	Limited	No	Seconds	No	No
DCSim	-	Open Source	Java	Yes	No	No	Minutes	No	No
MR-CloudSim	CloudSim	Not Available	Java	Yes	No	Limited	-	Yes	Yes
SmartSim	CloudSim	Open Source	Java	Yes	No	Limited	Seconds	Yes	Yes
SimIC	SimJava	Open Source	Java	Yes	No	Limited	Seconds	Rough	Yes
SPECI	SimKit	Open Source	Java	No	No	Limited	Seconds	Rough	No
Dynamic CloudSim	CloudSim	Open Source	Java	Yes	No	Limited	Seconds	Yes	Yes
CloudSimSDN	CloudSim	Open Source	Java	Yes	Yes	Full	Seconds	Yes	Yes
secCloudSim	iCanCloud	Not Available	C++	Yes	Yes	Full	Seconds	No	No
CEPSim	CloudSim	Not Available	Java	Yes	Yes	Limited	Seconds	Yes	Yes
PICS	-	Open Source	Python	Yes	No	No	Seconds	No	No

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