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Cloud Computing Simulation Tools - A Study

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Abstract. Cloud computing eliminates the need for maintaining expensive computing facilities. The characteristics of a typical cloud are: on-demand access, scalability, elasticity, cost reduction, minimum management effort, and device/location independence. As the adoption and deployment of cloud computing increases, it is critical to evaluate the performance and other issues. To model and schedule the different applications and services for cloud infrastructure system is a tremendous challenging task which requires different load and energy performance configurations. This can be solved by using various simulation tools. Several cloud simulators have been specifically developed for performance analysis of cloud computing environments.This paper briefly explores the concept of cloud computing and surveys several features of the various simulation tools.

Keywords: Cloud computing, simulation tools, data center

AMS Mathematics Subject Classification (2010): 68-02

1. Introduction

The cloud computing phenomenon has come to stay for good. It has made a fast and a giant leap towards the commercial arena from the academic and the scientific circles. There are many definitions of cloud computing proposed by various academicians, columnists, renowned persons in the industry as well as by some prominent standards setting organisations and major government departments. One of the most universally accepted definition of cloud computing comes from the National Institute of Standards and Technology, U.S. Department of Commerce. It is given as follows:

“Cloud Computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models”[1].

2. Preliminaries

2.1. Essential characteristics

On-demand self-service: A consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with each service provider.

Broad network access: Capabilities are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, tablets, laptops, and workstations).

Resource pooling: The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. Examples of resources include storage, processing, memory, and network bandwidth.

Rapid elasticity: Capabilities can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward, commensurate with demand.

Measured service: Cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be monitored, controlled, and reported, providing transparency for both the provider and consumer of the utilized service.

2.2. Service models

Software as a Service (SaaS): The consumer uses the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through either a thin client interface, such as a web browser, or a program interface. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.

Platform as a Service (PaaS): The consumer deploys onto the cloud infrastructure consumer-created or acquired applications created using programming languages, libraries, services, and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment.

Infrastructure as a Service (IaaS): The consumer provisions processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications; and possibly limited control of select networking components (e.g., host firewalls).

2.3. Deployment models

Private cloud: The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by the organization, a third party, or some combination of them, and it may exist on or off premises.

Community cloud: The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of them, and it may exist on or off premises.

Public cloud: The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization, or some combination of them. It exists on the premises of the cloud provider.

Hybrid cloud: The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds)[1,2].

2.4. NIST cloud computing architecture

Further the NIST cloud computing reference architecture defines five major actors: cloud consumer, cloud provider, cloud carrier, cloud auditor and cloud broker. Each actor is an entity (a person or an organization) that participates in a transaction or process and/or performs tasks in cloud computing as shown in fig.1 [3].

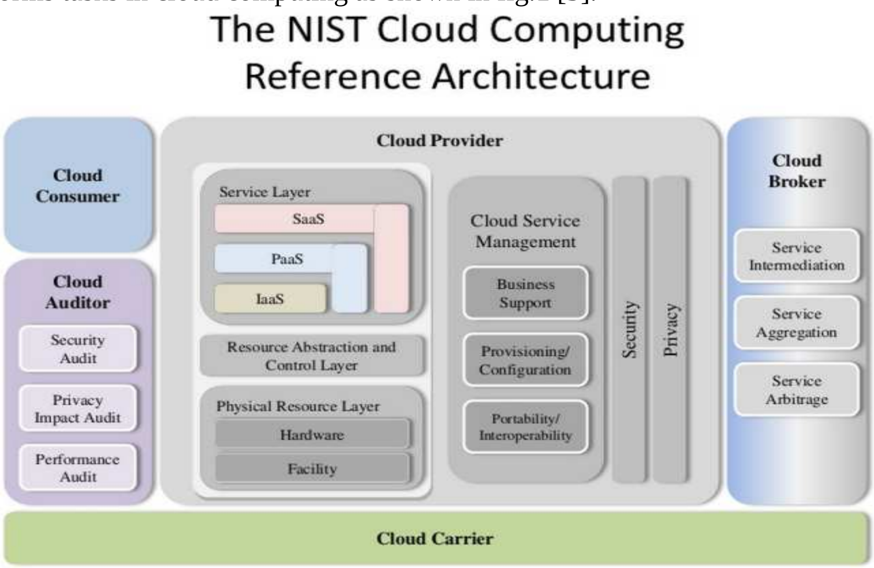

Figure 1: Layered cloud computing architecture [3]

The Cloud Broker acts as the intermediate between consumer and provider and will help consumers through the complexity of cloud service offerings and may also create value-added cloud services as well. The Cloud Auditor provides a valuable inherent function for the government by conducting the independent performance and security monitoring of cloud services. The Cloud Carrier is the organization who has the responsibility of transferring the data akin to the power distributor for the electric grid.

A Cloud Provider has to set up a virtualized data center to provide services to the Cloud Consumer. A data center has the following virtualized components:

- **Application** is a computer program that provides the logic for computing operations. Applications may use a DBMS, which uses operating system services, to perform store/retrieve operations on storage devices.
- **DBMS** provides a structured way to store data in logically organized tables that are interrelated. A DBMS optimizes the storage and retrieval of data.
- **Compute** is a resource that runs applications with the help of underlying computing components.
- **Storage** is a resource that stores data persistently for subsequent use.
- **Network** is a data path that facilitates communication between compute systems or between compute systems and storage.

Many industries, organisations and institutions are turning to clouds. When these entities want to adopt the cloud, they have to reassure them selves that they have made an apt decision. It is very difficult and next to impossible to use the real life cloud infrastructures to evaluate the cloud application performance for various possibilities. This is where the cloud simulation tools come to the aid of those developing the cloud applications and also to those who are contemplating of migrating to the cloud for definite reasons. There are many simulators that are available as open source as well as proprietary. Following section is about the various cloud simulation tools including their respective architectures.

3. Cloud simulation tools

3.1. CloudSim

CloudSim is a simulation application which enables seamless modelling, simulation, and experimentation of cloud computing and application services[4]. CloudSim offers the following novel features: (i) support for modelling and simulation of large-scale Cloud computing environments, including data centers, on a single physical computing node; (ii) a self-contained platform for modelling Clouds, service brokers, provisioning, and allocation policies; (iii) support for simulation of network connections among the simulated system elements; and (iv) facility for simulation of federated Cloud environment that inter-networks resources from both private and public domains, a feature critical for research studies related to Cloud-Bursts and automatic application scaling. The architecture is shown in fig. 2.

3.2. CloudAnalyst

CloudAnalyst, a simulator with GUI, was derived from CloudSim and extends some of its capabilities and features proposed. CloudAnalyst separates the simulation experimentation exercise from a programming exercise. It also enables a modeller to repeatedly perform simulations and to conduct a series of simulation experiments with slight parameters variations in a quick and easy manner. CloudAnalyst can be applied to examining behavior of large scaled Internet application in a cloud environment [5]. The CloudAnalyst also allows users to save a simulation configuration as a xml file and also the exporting of results into PDF format. It is a tool that concentrates on modelling rather than the programming technicalities.

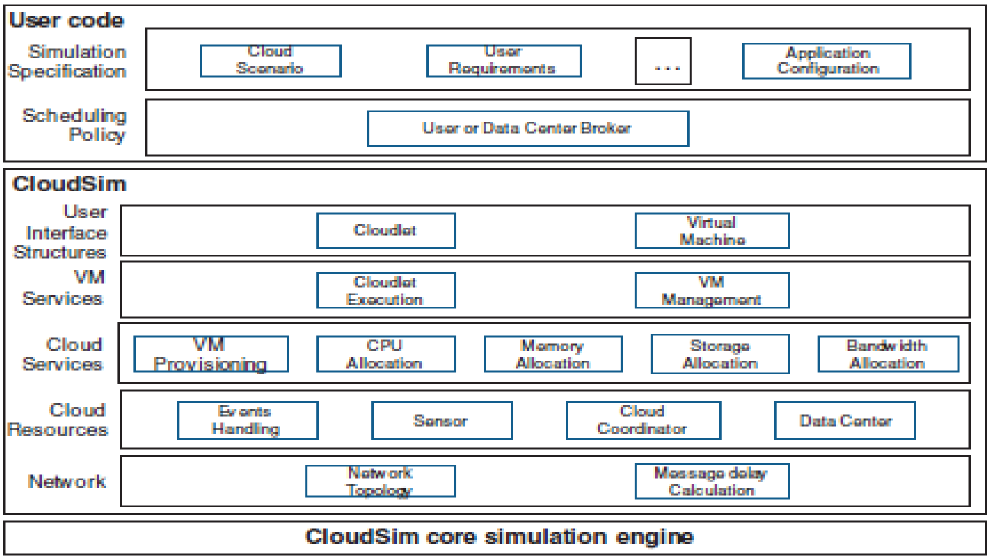

Figure 2: Layered CloudSim architecture [4]

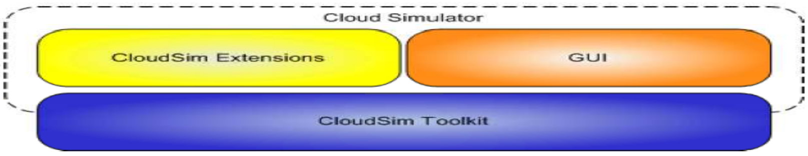

Figure 3: CloudAnalyst built on top of CloudSim [5]

3.3. GreenCloud

The GreenCloud simulator provides simulation environment for energy-aware cloud computing data centers. Along with the workload distribution, the simulator is designed to capture details of the energy consumed by data center components (servers, switches, and links) as well as packet-level communication patterns in realistic setups. GreenCloud is developed as an extension of a packet-level network simulator Ns 2. GreenCloud extracts, aggregates, and makes information about the energy consumed by computing and communication elements of the data center. It is devoted to accurately capture communication patterns of currently deployed and future data center architectures. Specifically GreenCloud distinguishes three energy consumption components: (a) computing energy, (b) communicational energy, and (c) the energy component related to the physical infrastructure of a data center. To be precise GreenCloud is designed to capture details of the energy consumed by data center components as well as packet-level communication patterns between them [6]. Fig. 4 presents the structure of the GreenCloud extension mapped onto the three-tier data center architecture.

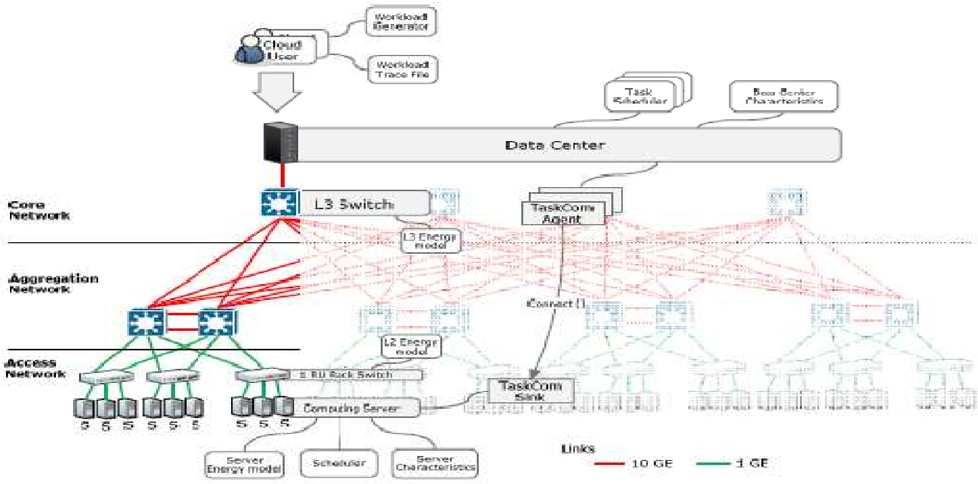

Figure 4: Architecture of the GreenCloud simulation environment [6]

3.4. NetworkCloudSim

NetworkCloudSim is equipped with network flow model for Cloud data centers utilizing bandwidth sharing and latencies to enable scalable andfast simulations. Most of the parameters are configurable, allowing researchers to simulate a wide variety of network topologies. But it limits its scalability to only small data centers due to large simulation time and high memory requirements. There are three main actors (or Entities) in the NetworkCloudSim: Switch, NetworkDatacenter, and NetworkDatacenterBroker. NetworkCloudSim helps in the development of more power efficient resource management schemes rapidly before committing time and resources in building complex software and network systems that operate within Cloud data centers. NetworkCloudSim extends CloudSim with a scalable network and generalized application model, which allows more accurate evaluation of scheduling and resource provisioning policies to optimize the performance of a Cloud infrastructure. [7].Fig. 5 shows how new structure and functionality of complex parallel and distributed applications can be modelled in NetworkCloudSim.

2.5. EMUSIM

EMUSIM is an integrated architecture to anticipate service's behavior on cloud platforms to a higher standard [8]. EMUSIM combines emulation and simulation to extract information automatically from the application behavior via emulation and uses this information to generate the corresponding simulation model. Such a simulation model is then used to build a simulated scenario that is closer to the actual target production environment in application computing resources and request patterns. Information that is typically not disclosed by platform owners, such as location of virtual machines and number of virtual machines per host in a given time, is not required by EMUSIM. EMUSIM is built on top of two software systems: Automated Emulation Framework (AEF) for emulation and CloudSim for simulation. Fig. 6 depicts the internal organization of EMUSIM and the role of each component.

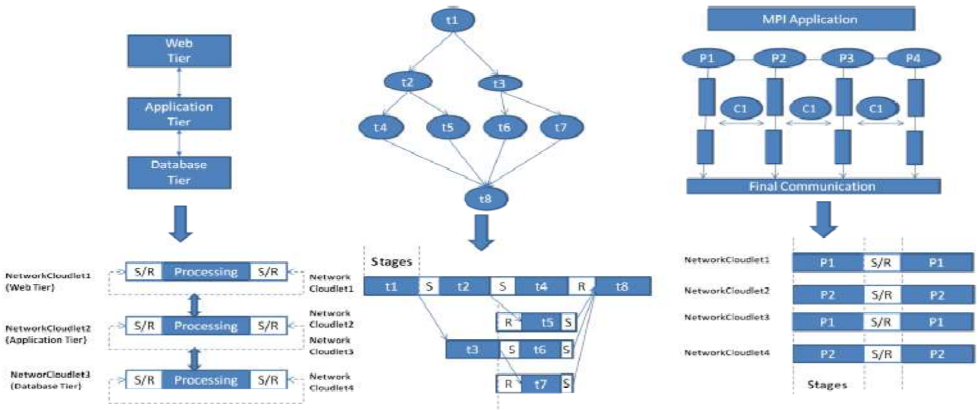

Figure 5: Modelling of applications inNetworkCloudSim[7]

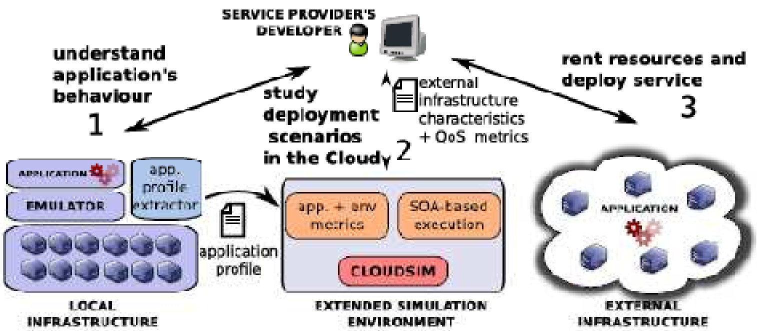

Figure 6: EMUSIM organization overview [8]

3.6. MDCSim

MDCSim is a commercial discrete event simulator developed at the Pennsylvania State University. It helps the analyzer to model unique hardware characteristics of different components of a data center such as servers, communication links and switches which are collected from different dealers and allows estimation of power consumption. MDCSim is the most prominent tool to be used as it has low simulation overhead and moreover its network package maintains a data center topology in the form of directed graph.[9] The architecture is shown in fig. 7.

Network Interface Card (NIC) and Disk are devices and others are processes that reside inside the CPU in a server node. It is assumed that CPU, Disk and NIC are basic computing resources in a node responsible to process requests. The simulation is configured into three layers (a communication layer, a kernel layer and a user-level layer) for modelling the entire stack starting from the communication protocols to the application specifics. Such a three layer abstraction provides the flexibility and scalability in analyzing various design details as described next. Intra-cluster communication is modelled at the communication layer.

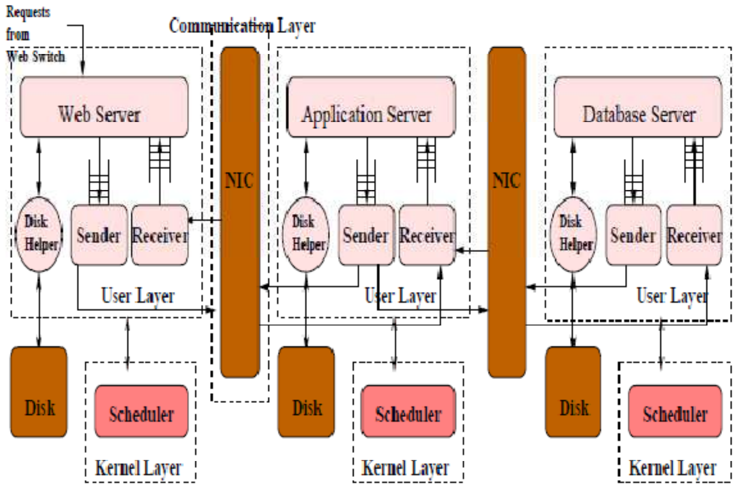

Figure 7: Architectural details of the three layers of the simulator [9]

3.7. FTCloudSim

FTCloudSim provides an extensible interface to help researchers implement new cloud service reliability enhancement mechanisms. In addition, FTCloudSim can also study the behavior of the new proposed mechanisms. FTCloudSim is a CloudSim-based tool which can model and simulate the cloud service reliability enhancement mechanisms. An extensible interface is provided in FTCloudSim to aid researchers in implementing new mechanisms easily. In addition, FTCloudSim can trigger failure events to test the performance of each mechanism. After execution, it will generate information on the necessary metrics to highlight the advantages and shortcomings of the mechanism. Almost all the reliability enhancement methods are based on the exploitation of redundancy. Replication and checkpointing are two widely used basic mechanisms. FTCloudSim can support checkpointing based fault-tolerant mechanism currently. As shown in Fig. 8, FTCloudSim has added 6 modules to CloudSim: fat-tree data center network construction, failure and repair event triggering, checkpoint image generation and storage, checkpoint-based cloudlet recovery, and results generation [10]. Fig. 8 shows the four layers of FTCloudSim.

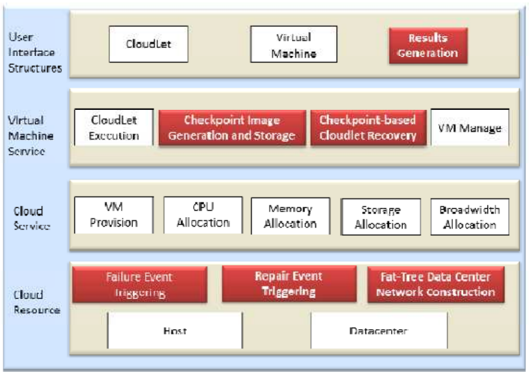

Figure 8: FTCloudSimframework [10]

3.8. DCSim

DCSim (Data Centre Simulator) is an extensible data centre simulator implemented in Java, designed to provide an easy framework for developing and experimenting with data centre management techniques and algorithms [11]. It is an event-driven simulator, simulating a data centre offering IaaS to multiple clients. It focuses on modelling transactional, continuous workloads (such as a web server), but can be extended to model other workloads as well. Fig. 9 outlines the main components of DCSim. The primary class is the DataCentre, which contains Hosts, VMs, and various management components and policies. DCSim allows researchers to quickly and easily develop and evaluate dynamic resource management techniques. It introduces key new features not found in other simulators, including a multi-tier application model which allows the simulation of dependencies between VMs, VM replication as a tool for handling increasing workload, and the ability to combine these features with a work conserving CPU scheduler.

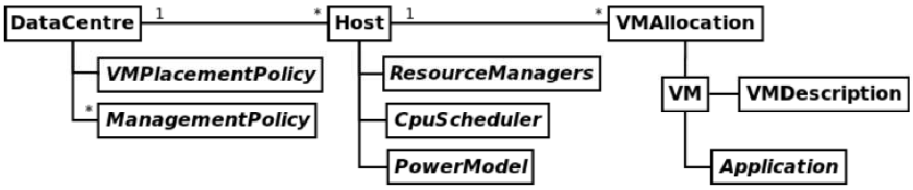

Figure 9: DCSimArchitecture [11]

3.9. GDCSim

The Green Data Center Simulator (GDCSim) unifies the simulation of management techniques with a simulation of the physical behavior of a data center[12]. It can be used by data center designers, operators and researchers for developing green data centers of the future. GDCSim has the following components: (i) BlueSim, that takes a high level XML based specification as input and performs CFD simulations to output a heat recirculation profile of the data center for fast thermal evaluation; (ii) Resource management, that makes informed decisions about workload and cooling management based on physical behavior of data center; (iii) Simulator, that captures the physical behavior of the data center in response to the management decisions and provides feedback to the resource management for awareness of the changes in data center physical behavior. This shown in fig. 10. GDCSim is envisioned to be modular and extensible. Modularization ensures that the different components of GDCSim can be used independently. For example, the CFD simulator module, BlueSim, can be used solely for generating the thermal map of the data center and may not be used in conjunction with the resource management module. Extensibility ensures that new models and assumptions can be easily plugged into the simulator.

3.10. CDOSim

During a cloud migration a cloud user has to assess a wide range of different cloud deployment options (CDOs). For example, a selection of a cloud provider must be conducted. Furthermore, the mapping between services and virtual machine instances must be considered. The virtual machine instances' configuration and adaptation strategies must be also specified. Rewriting and testing the software with the different cloud deployment options is infeasible. Simulating the different deployment options can assist to find the best ratio between high performance and low costs. Thus the evaluation of competing cloud deployment options (CDOs) forms a major challenge when migrating software systems to cloud environments. A plethora of potential cloud provider candidates, components must be mapped to suitable virtual machine instances, and, to exploit elasticity, appropriate runtime adaptation strategies for specific usage profiles have to be defined. But analyzing potential CDOs manually is intractable, costly, and time consuming due to the heterogeneity of the cloud environments and the overall combinatorial design space complexity.

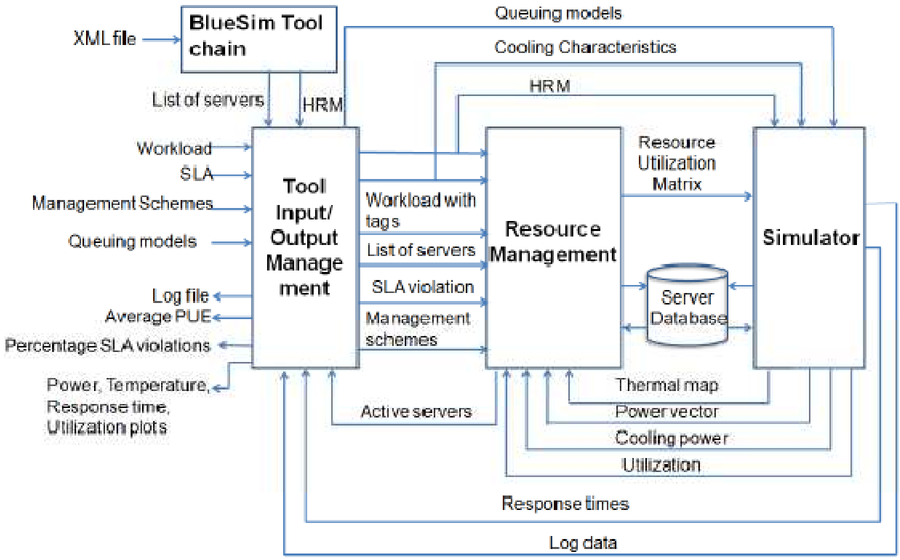

Figure 10: GDCSim tool architecture [12]

The simulation tool CDOSim can simulate the response times, SLA violations, performance and costs of a CDO. It builds upon and significantly extends the cloud simulator CloudSim and integrates into the cloud migration framework CloudMIG. The integration with CloudMIG Xpress is depicted in Fig 11.

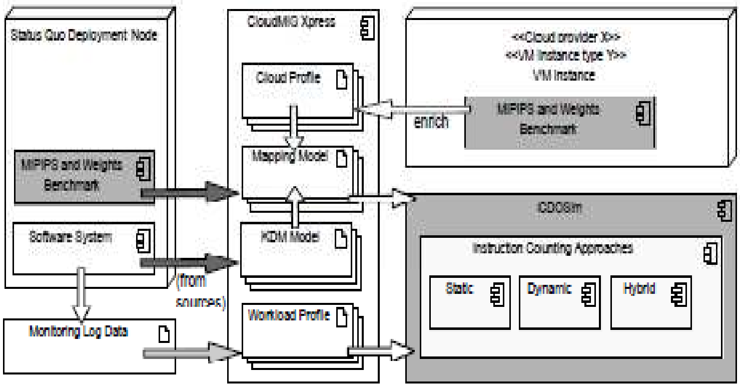

Figure 11: Integration of CDOSim with CloudMIGXpress [13]

3.11. GroudSim

GroudSim is an event based simulator for scientific applications on Grid and Cloud environments. GroudSim can also be described as a Grid and Cloud simulation toolkit for scientific applications based on a scalable simulation-independent discrete-event core. GroudSim provides a comprehensive set of features for complex simulation scenarios from simple job executions on leased computing resources to calculation of costs, and background load on resources. Simulations can be parameterised and are easily extendable by probability distribution packages for failures which normally occur in complex environments. SimEngine is the main GroudSim class which implements the time advance algorithm, the clock, and the Future Event List, and keeps track of the registered entities used for tracing during a simulation. GroudSim offers some basic statistics and analysis views after runtime to allow the user to easily writer more complex analysis. The developed simulation framework supports modelling of Grid and Cloud computational and network resources, job submissions, file transfers, as well as integration of failure, background load, and cost models [14]. The architecture is shown in fig. 12.

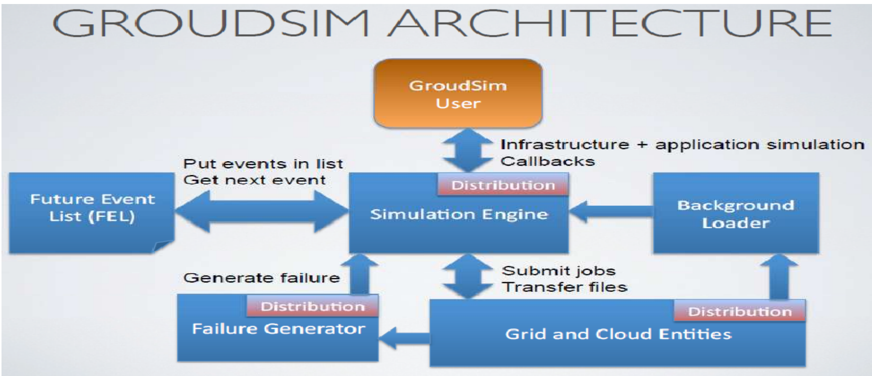

Figure 12: GroudSim Architecture [15]

3.12. SPECI

SPECI stands for Simulation Program for Elastic Cloud Infrastructures. It is a simulation tool that enables exploration of scaling properties of large data centres. It simulates the performance and behaviour of data centres, given the size and middleware design policy as input. It allows exploration of aspects of scaling as well as performance properties of future DCs. SPECI also deals with inconsistencies that arise after failures occur. It can be shown with SPECI that when the size and failure rate of the DC increases, a distributed DC management becomes favourable [16].

3.13. TeachCloud

TeachCloud provides advanced workload modelling capabilities by introducing the Rain workload generator framework from the University of California at Berkeley. TeachCloud is a comprehensive, easy-to-use, and efficient cloud computing modelling and simulation toolkit. TeachCloud fills a large gap in teaching cloud computing caused by the lack of such a comprehensive and easy-to-use tool, in addition to the high-risks and costs of allowing students to experiment using a real cloud system. TeachCloud provides a rich, yet simple, GUI to build cloud infrastructure and present results and charts. TeachCloud allows a user to customize all aspects in a cloud infrastructure from the host processing nodes to the network topology. TeachCloud makes it easy for users to comprehend the different cloud system components and their roles in the whole system. Users can modify the different components and their parameters, run simulations, and analyze results [17].

4. Conclusion

Cloud computing is one of the fastest growing fields in IT industry. It is necessary to evaluate performance and security risks that are inherent part of cloud computing, as the users are worried about security problems and other cost related issues that exist with the prevalent implementation of cloud computing. Various simulators have been developed especially for performance analysis of cloud computing environments. Simulation-based approaches are more acceptable in industry and academia for the conveniently assess cloud computing systems, application behaviors and their security. In this review paper, we have discussed a few cloud simulation tools. Certain tools may be more suitable than the other as every tool has some advantage or limitation over the other. So, the users will have to select the tools according to their specific requirements. This paper discusses the basics of cloud computing and its available simulators. There are continued efforts to improve, expand and develop the models, and simulators especially for cloud computing environments.

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