International Conference on Multidisciplinary Perspectives in Advanced Computing and Technology (IMPACT 2026)
G. B. Pant University of Agriculture and Technology, Uttarakhand, India. Jan. 10-11, 2026

A Study on CloudSim Framework for Cloud Simulation Environments

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ABSTRACT

In today's information technology landscape, cloud computing serves as a critical infrastructure for scalable, on-demand computing services. Testing new methods for resource distribution, workload scheduling, and operational effectiveness in cloud platforms can be expensive, time-consuming, and difficult to reproduce. Simulation frameworks such as CloudSim allow researchers to model and analyze cloud environments in a controlled and cost-effective way. This study reviews the framework's architecture, main features, simulation capabilities, and key extensions. Its modular design lets researchers run experiments with data centers, virtual machines, and even newer stuff like edge computing and IoT. Sure, it doesn't capture every messy detail of real cloud operations, but it's a practical way to test out scheduling algorithms, energy-saving resource management, load balancing, and ways to cut costs without spending a fortune. Looking ahead, it makes sense to add features such as container support, more realistic energy models, and better simulations that accurately reflect how today's cloud systems operate.

Keywords: *Cloud Computing, CloudSim, Cloud Simulation, CloudSim Architecture, Simulation Capabilities, Energy Efficiency, Scheduling*

1. Introduction

Cloud computing has changed the way we handle information technology. Now, organisations have instant access to computing power, storage, networking, and a wide range of applications whenever they need them [1], [2]. Main service models, such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS), make it easier to deploy and manage these resources. It's easier to scale up, adapt, and save on costs [3]. As more businesses and researchers lean on cloud systems, people are digging into ways to make them work even better. They're looking at how to allocate resources, schedule tasks, cut down energy use, and keep costs low [4], [6]. But there's a catch: conducting direct testing on major commercial cloud providers can be expensive, time-consuming, and difficult to reproduce. It gets expensive, it can be complicated, and with all the changing settings and unpredictable workloads, it's tough to get consistent, repeatable results [7]. To overcome these challenges, simulation tools provide a controlled and cost-effective environment for evaluating cloud performance and testing novel algorithms [8]. Among these tools, CloudSim, developed by the CLOUDS Laboratory at the University of Melbourne, has emerged as one of the most comprehensive and widely used frameworks for modeling and simulating large-scale cloud ecosystems [9]. It allows researchers to design customizable experiments involving data centers, virtual machines, and workloads under reproducible conditions [10]. CloudSim provides a number of key benefits, most notably its ability to model and experiment with cloud environments on a very large scale. support for diverse research scenarios, ease of modeling complex applications, energy-aware resource management, and cost-efficient experimentation without requiring physical infrastructure [9], [11]. Despite these benefits, CloudSim also has limitations, including no built-in GUI, minimal network modeling capabilities, and limited suitability for parallel experiments, and often requires exporting simulation data to external tools for in-depth analysis [12], [13]. This paper presents a review of the CloudSim framework, focusing on its architecture, features, simulation capabilities, research applications, and future directions. The aim is to provide researchers with a clear understanding of CloudSim's evolution, its strengths and limitations, and its role in advanced computing studies [9], [14], [15].

2. Cloud Computing and the importance of Simulation Frameworks

Cloud computing delivers immediate access to shared online resources, including servers, storage systems, and applications [1], [2]. This setup lets users access flexible, scalable resources without investing in dedicated infrastructure or maintaining physical hardware [3]. Large-scale data centers host diverse workloads, supporting a wide variety of services efficiently [4]. However, testing new algorithms, scheduling techniques, or resource management strategies in real cloud environments is often expensive, time-consuming, and difficult to reproduce due to dynamic workloads and network variability [5], [6], [7]. Simulation frameworks address these challenges by providing controlled, virtual environments for experimentation [8]. Among them, CloudSim offers an open-source, extensible platform for modeling cloud infrastructures, enabling researchers to implement and evaluate algorithms for resource allocation, scheduling, and performance optimization without incurring the cost of physical infrastructure [9], [11], [12].

2.1. Factors for Adopting CloudSim for Modeling and Simulation

CloudSim has become a widely adopted toolkit for cloud computing research and experimentation due to its extensive simulation capabilities. It provides researchers with a controlled environment to model, evaluate, and analyse different aspects of cloud infrastructures before real-world deployment.

- It supports modelling of multiple cloud computing data centres, enabling large-scale infrastructure evaluation [11].
- It enables the use of purpose-specific software containers for application testing [41].
- It supports power-aware computational resources, allowing energy-efficient simulation studies [11].
- It supports dynamic addition or removal of simulation components, providing flexibility for complex simulation scenarios [40].

- It allows simulations to be paused and resumed, offering experiment control during execution [11].

2.2. Benefits of CloudSim Simulation

The CloudSim includes several advantages that enhance its overall effectiveness and has become an attractive choice for academic and industrial research:

- It provides elasticity for large-scale configurations, allowing simulations of extensive cloud environments [11].
- It supports a variety of cloud environments, accommodating diverse research and application scenarios [11], [40].
- It enables modeling of application services across different cloud infrastructures [41].
- It facilitates rapid implementation of cloud-based applications with minimal time and effort [11].
- It offers ease of use and high customizability, allowing researchers to define their own policies and test various approaches to managing resources. [41].

2.3. Constraints of CloudSim Simulation

Despite its advantages, CloudSim also presents several limitations:

- It lacks a visual user interface that supports the generating and visualizing results [11].
- It provides less support for workload transfer modeling due to its basic network model [10].
- It is not ideal for modeling parallel experiments efficiently [10].
- Analysing simulation results can be challenging and time-consuming [41].
- Researchers need to export data to external tools, such as Excel, for detailed analysis [11].

3. Overview and Evolution of CloudSim

CloudSim, developed in 2009 by the CLOUDS Laboratory at the University of Melbourne, is a simulation framework designed for modeling and analyzing large-scale cloud computing infrastructures [1], [2]. The toolkit enables researchers to emulate essential cloud components, including data centers, hosts, and virtual machines (VMs), in a controlled and reproducible environment [3]. Written entirely in Java, it provides platform independence and supports easy coordination and linkage with other Java-based tools [4]. CloudSim offers a cost-effective solution for evaluating various cloud scenarios, such as task scheduling, resource management, and energy-aware optimization. Over time, numerous extensions and functional upgrades have been incorporated into the framework, such as multiple extensions, improving its realism, flexibility, and usability for diverse research applications.

- **GridSim (2002–2008):** CloudSim has its roots in GridSim, which was developed specifically to facilitate the simulation of distributed grid systems [5]. It lacked cloud-specific features like virtualization, elastic scaling, and on-demand provisioning.
- **CloudSim (2009):** The initial version by Rajkumar Buyya et al. introduced a unified platform for simulating data centers, virtual machines, and brokers [7]. It allowed researchers to evaluate resource allocation, scheduling strategies, and cost–performance trade-offs in large-scale cloud setups [8].
- **CloudSim 2.x (2010–2011):** This update added dynamic entity insertion, federated cloud support, energy-aware resource modeling, and economic cost models, along with advanced scheduling techniques for SLA-based simulations [9], [10].
- **CloudAnalyst (2010):** A GUI extension enabling visual simulation of large-scale internet applications, focusing on workload distribution, response time, and cost evaluation [11].
- **NetworkCloudSim (2012):** Introduced modeling of network and communication aspects, supporting studies of network-intensive and parallel applications [12].
- **GreenCloud & CloudSimEnergy (2012–2013):** These extensions focused on energy-efficient simulations, allowing analysis of power consumption and energy–performance trade-offs [13], [14].
- **CloudSimSDN (2014–2016):** It includes built-in capabilities for Software-Defined Networking (SDN), which allow programmable network behavior and QoS-based routing within simulation environments [15].
- **IoTCloudSim & CloudSimIoT (2016–2018):** Expanded capabilities for IoT, simulating sensors, fog nodes, and heterogeneous edge-cloud interactions [16], [17].
- **EdgeCloudSim (2018–2019):** Tailored for edge computing, supporting user mobility, multi-tier interactions, and latency-sensitive applications [18].
- **CloudSim Plus (2017–Present):** A modern rewrite in Java 8+, emphasizing modularity, extensibility, and multi-threaded simulation support [19].
- **Recent development 2020–Present):** Ongoing research includes containerized/serverless simulation and intelligent scheduling for hybrid/multi-cloud systems [20], [21].

4. CloudSim Architecture

The CloudSim framework employs a modular and layered architecture, providing researchers with a flexible and extensible platform for modeling and analyzing complex cloud computing systems [1], [2]. Its layered structure allows simulation parameters to be specified at different levels of abstraction, supporting scalability, adaptability, and reusability [3]. This design also enables the incorporation of customized algorithms, resource management strategies, and performance assessment mechanisms that support multiple types of research scenarios, including workload scheduling and energy-efficient management [4]. Each architectural layer has a well-defined role, interacting seamlessly with others to deliver accurate and comprehensive cloud simulations [5], [6]. The framework consists of several key building blocks, and every unit is tasked with reproducing one aspect of cloud infrastructure.

- **Modular and Layered Design:** Flexible and extensible platform for cloud simulation [1], [2].
- **Simulation Engine:** Manages event sequencing, synchronization, and dynamic behaviours [1], [7], [8].
- **Data Center & Host Layer**: Models physical infrastructure, resources, and host configurations [9], [10].
- **Virtual Machines (VMs):** Represents virtualized resources executing cloudlets; supports space-shared and time-shared scheduling [3], [11], [12].
- **Broker & Cloudlet Layer:** Handles task submission, VM provisioning, and workload mapping; evaluates QoS and performance [1], [13], [14].
- **Policy Layer:** Implements custom strategies for resource allocation, load balancing, energy efficiency, VM migration, and SLA-based operations [9], [15], [17].

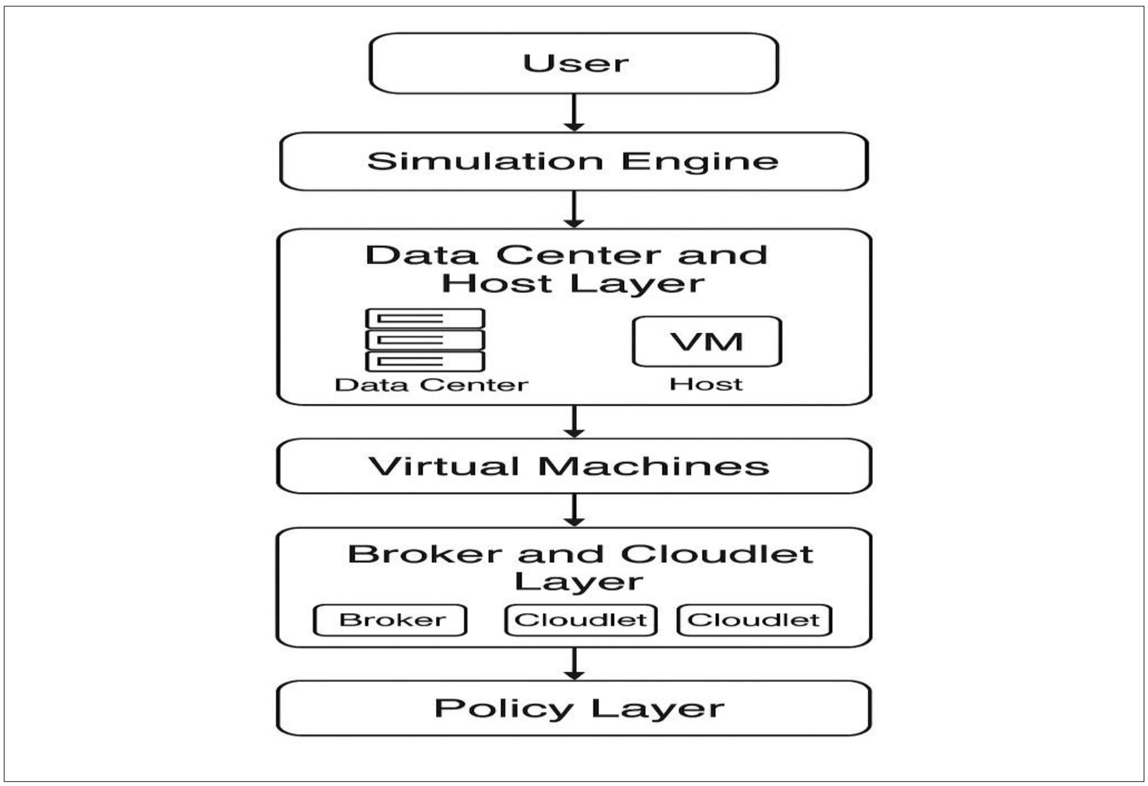

Figure 1: CloudSim Architecture: The architecture of CloudSim illustrating its modular and layered structure (Adapted from [7], [9], [42]).

5. Key Features of CloudSim

CloudSim offers versatile features for modeling and evaluating cloud scenarios, including resource allocation, task scheduling, energy efficiency, and cost optimization [1], [2]. Its modular and extensible design supports research in cloud, edge, and fog computing environments [3].

The key features of CloudSim are summarized below:

- **Resource Modeling:** CloudSim enables precise representation of system resources such as processing power, memory capacity, storage units, and network throughput [1]. It supports heterogeneous environments, enabling realistic simulation of diverse data center architectures [4].
- **Energy Awareness:** The framework includes energy models for hosts, supporting power-aware scheduling and dynamic consolidation to study energy-efficient strategies [5], [6].
- **Cost and Pricing:** Configurable pricing models, such as pay-as-you-go or subscription-based, allow analysis of cost-performance trade-offs in cloud services [2], [7].
- **Scalability:** CloudSim can simulate multiple data centers, thousands of hosts, and tens of thousands of VMs, making it suitable for large-scale studies [1], [8], [9].
- **Extensibility:** Its modular, open-source design supports extensions for fog, edge, and IoT systems, such as CloudSimSDN and CloudSim Plus [3], [10], [11].
- **Trace-Driven Simulation:** Users can import real workload traces to validate algorithms under realistic conditions [12], [13].

6. Simulation capabilities

CloudSim is a flexible and extensible platform designed to model and analyze cloud-based environments, allowing researchers to test and evaluate resource management and scheduling strategies under controlled conditions [1], [2]. It supports experiments with task scheduling algorithms like Min-Min, Max-Min, and Round Robin to analyze performance metrics including measures like overall system throughput, response time, and system efficiency [3]. The toolkit also enables energy-aware simulations, modeling host-level power consumption and supporting techniques like VM consolidation and dynamic load balancing to minimize power consumption while still ensuring Quality of Service (QoS) [4], [5], [6]. CloudSim allows Service Level Agreements based studies, measuring indicators such as task completion rate, availability, and response time [7]. Additionally, it can simulate multi-cloud and hybrid environments, facilitating research on load distribution, cost optimization, and resource management across heterogeneous infrastructures [8], [9]. Key metrics such as makespan, CPU utilization, throughput, and energy consumption provide a complete view of system performance [10].

6.1. Major Extensions of CloudSim

CloudSim has evolved with several extensions to support emerging cloud, fog, and edge computing paradigms, enhancing simulation realism and research applicability [11], [12].

- **CloudSim Plus:** A modern, object-oriented version written in Java 8+, CloudSim Plus improves modularity, multi-threaded simulations, and energy modeling, helping researchers study performance–energy trade-offs in large-scale data centers [13], [14].
- **iFogSim:** Designed for fog and IoT scenarios, iFogSim models sensors, actuators, and fog nodes, enabling research on latency-sensitive applications, offloading strategies, and energy-aware scheduling [15], [16].

- **EdgeCloudSim:** Focused on edge computing, this extension simulates user mobility, heterogeneous devices, and network delays, supporting evaluation of resource provisioning and application placement [17].
- **CloudAnalyst:** Provides a GUI for configuring, running, and visualizing cloud experiments, simplifying comparisons of scheduling and load-balancing policies [18].
- **CloudSimSDN / CloudSimSDN-NFV:** Incorporates SDN and NFV features to simulate programmable networks, virtualized network functions, and service chaining in cloud infrastructures [19].
- **GreenCloudSim:** Adds energy-aware capabilities for host, VM, and data center levels, supporting VM migration and thermal-aware scheduling for sustainable operations [20], [21].
- **NetworkCloudSim:** Enhances network modeling, including bandwidth constraints and communication delays, for evaluating network-intensive applications [22], [23].

Table 1: Comparative Evaluation of CloudSim and Related Simulation Frameworks

Framework	Language	Ease of Use	Key Features	Target Domain	Maintenance	Reference
CloudSim	Java	Moderate	Core simulation for data centers, VMs, scheduling, allocation	General cloud research	Stable, widely used	[7], [9], [40]
CloudSim Plus	Java (OOP)	Easy	Modern API, modular design, improved documentation	Research, algorithm testing	Actively maintained	[14]
GreenCloud	C++ / OTcl	Hard	Energy and packet-level network modeling	Energy-aware data centers	Limited, older project	[12], [33]
iFogSim	Java	Moderate	IoT, fog/edge nodes, latency and energy models	IoT and Edge Computing	Actively used	[15], [31]

CloudAnalyst	Java	Easy	GUI-based workload modeling and analysis	Education, quick experiments	Older, limited updates	[11]
EdgeCloudSim	Java	Moderate	Edge devices, mobility, offloading	Edge computing	Open-source, active	[16]
CloudSimSDN	Java	Moderate	SDN modeling – switches, controllers, flow rules	SDN-enabled cloud systems	Moderate activity	[17]
NetworkCloudSim	Java	Moderate	Workflow and detailed network modeling	Networked applications	Research-level tool	[10]

6.2. Comparative Analysis and Discussion

A review of CloudSim and its major extensions highlights the framework's development into a versatile simulation platform. The original CloudSim enables modeling of core cloud components such as data centers, hosts, and virtual machines, supporting scalable and flexible research applications [7], [9]. CloudSim Plus enhances this framework with object-oriented architecture, modular design, and multi-threaded simulation, making it suitable for large-scale experiments [14]. GreenCloud adds detailed energy modeling to evaluate energy-efficient strategies in data centers [12], [33]. EdgeCloudSim and iFogSim extend CloudSim to IoT and edge environments, handling latency-sensitive and mobility-aware applications [15], [16], [31]. CloudAnalyst provides a graphical interface for simplified workload modeling and result visualization [11], while CloudSimSDN supports programmable and virtualized networking [17], [34]. Among these, CloudSim Plus and EdgeCloudSim are widely used due to their scalability and modern design [14], [16], [20]. The framework's modular, open-source nature makes it a standard tool for cloud, edge, and IoT simulation research [24], [31], [39].

7. Research Applications of CloudSim

CloudSim is a widely used simulation platform that enables controlled, flexible, and reproducible testing of cloud computing strategies [1], [2]. With a flexible, modular layout, it facilitates experimentation with different methods for organizing computational tasks, allocating resources, managing energy, and enforcing QoS [3].

- **Workload Distribution and Load Balancing:** CloudSim allows evaluation of algorithms like Min-Min, Max-Min, Genetic Algorithms, PSO, and DRL, assessing metrics such as response time, throughput, and resource utilization [4], [10].
- **Energy Efficiency:** Energy-aware modeling enables studies on VM consolidation, power-aware scheduling, and thermal management to reduce consumption while maintaining performance [11], [15].
- **Quality of Service (QoS):** Researchers can simulate SLA metrics including latency, throughput, and availability to test resource allocation and scheduling policies [16], [19].
- **Edge and IoT Simulation:** Extensions like iFogSim and EdgeCloudSim support latency-sensitive, distributed IoT environments, enabling analysis of task offloading and mobility-aware scheduling [20], [24].
- **Cost Optimization:** CloudSim supports economic modeling for pay-as-you-go, reservation-based, and dynamic pricing schemes, allowing study of cost-performance trade-offs in cloud environments [25], [29].

8. Future Directions

As cloud computing continues to evolve, frameworks like CloudSim must adapt to support emerging fields like edge computing, networks of interconnected smart devices, serverless computing, and containerization [30], [31]. Future developments should focus on increasing simulation realism, scalability, and support for modern distributed architectures.

- **Containerized and Serverless Simulation:** With the growth of containers and Function-as-a-Service (FaaS) platforms, future CloudSim versions should model microservices, container orchestration, and serverless execution. This would allow researchers to analyze dynamic scaling, cold-start latency, and resource allocation at a fine-grained level [32], [33].
- **AI and Machine Learning Integration:** Incorporating predictive and adaptive models can enable autonomous task scheduling, resource management, and anomaly detection within simulated environments, supporting energy-efficient and self-optimizing cloud systems [34].
- **Advanced Network Modeling:** Accurate simulation of 5G/6G, SDN, and latency-sensitive applications requires packet-level network modeling, congestion handling, and QoS-aware routing [35].
- **Improved Visualization:** Enhanced GUIs and real-time dashboards can simplify monitoring of workloads, VM migrations, and energy consumption, making simulation outputs easier to interpret [36].
- **Sustainability Modeling:** Integrating environmental impact metrics, renewable energy usage, and carbon-aware scheduling can help evaluate eco-friendly cloud strategies [37].

9. Conclusion

In conclusion, CloudSim provides a flexible and reliable platform for simulating and evaluating cloud ecosystems, enabling researchers to study resource allocation, task scheduling, energy consumption, and cost management under reproducible conditions. Its modular and extensible architecture supports diverse experiments, making it suitable for both academic and industrial applications. The framework's evolution through extensions such as CloudSim Plus, EdgeCloudSim, and iFogSim has expanded its capabilities to model edge computing, IoT, and latency-sensitive systems, offering a realistic simulation of complex infrastructures. While CloudSim enables scalable and cost-effective experimentation, limitations remain, including restricted support for containerized and serverless computing and limited network-level modeling. Future work should focus on incorporating modern deployment models, improving network simulation, and enhancing visualization tools to support more intuitive analysis. Overall, CloudSim remains a valuable research tool, empowering the design, testing, and optimization of cloud, edge, and distributed computing systems efficiently and effectively.

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