

An energy-efficient cloud data center architectural model for the national data center of Bangladesh

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Abstract

This study presents an energy-efficient cloud data center architecture concept for Bangladesh's National Data Center. To reduce energy consumption and operational expenses, the model employs virtualization and load-balancing techniques, as well as renewable energy sources. The simulation results demonstrate that the model may drastically cut energy usage while maintaining high levels of performance and dependability. This research contributes to the worldwide challenge of climate change by offering a long-term solution for reducing the environmental effect of cloud data centers while maintaining the quality of cloud computing services.

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I. Introduction

Data centers are becoming more energy-intensive, which is a major problem due to rising energy costs and the need to minimize carbon emissions. The need for data centers in Bangladesh has been constantly increasing, and the energy consumption of data centers is a major concern.

This study presents an energy-efficient cloud data center architecture model capable of lowering energy usage and carbon emissions while

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maintaining data center performance and dependability. The Green Cloud Simulator will be used in the study to assess the energy consumption and performance of the proposed architecture under various workload and traffic scenarios.

The research will concentrate on constructing an environmentally friendly cloud computing engineering model, implementing the proposed architecture in the National Data Center of Bangladesh, evaluating the energy consumption and performance of the proposed architecture under multiple workloads and flow conditions, and comparing the energy utilization and performance of the suggested architecture to the existing data center architectural at the National Data Center of Bangladesh.

The study will provide useful insights into the energy-efficient design of data centers, which can be reproduced in other data centers in Bangladesh and worldwide. The study's findings will serve to inform the development of more sustainable data center layouts that can help to lessen the environmental impact of cloud computing.

The following are some of the summary's main points:

- Data centers are becoming increasingly energy-intensive.
- There is a need to develop energy-efficient cloud data center architectures.
- This research proposes an energy-efficient cloud data center architecture model.
- The study will use the Green Cloud Simulator to evaluate the proposed architecture.

II. Literature Review

The expansion of data centers has resulted in a rise in energy usage and greenhouse gas emissions, causing significant worries among policymakers, researchers, and industry experts. Consequently, several energy-efficient remedies have been devised for data centers, prompting the need for a literature review that examines and assesses the current body of research on energy-efficient architectures for cloud data centers. Furthermore, this review focuses on the implementation of these architectures using simulation tools like the Green Cloud Simulator. The literature presents different energy-efficient architectures for cloud data centers, including virtualization, consolidation, and dynamic resource allocation. Virtualization enhances resource utilization and energy

efficiency by creating virtual machines that share physical resources. Consolidation reduces energy consumption by consolidating workloads onto fewer servers. Dynamic resource allocation improves energy efficiency by allocating resources based on workload demand and reducing energy usage of idle servers. [3] Researchers have extensively utilized simulation tools to assess the effectiveness and energy efficiency of cloud data center architectures in numerous studies. The Green Cloud Simulator is a notable example of such a tool, enabling the evaluation of diverse energy-efficient cloud data center architectures and their performance across different scenarios. Many studies have employed the Green Cloud Simulator to assess the performance and energy efficiency of various cloud data center architectures, including virtualization, consolidation, and dynamic resource allocation. [5] While research on energy-efficient cloud data center architectures in Bangladesh is limited, some studies have explored energy-efficient solutions for data centers in developing countries. For instance, suggested an energy-efficient cloud data center architecture that employs renewable energy sources like solar and wind to decrease energy consumption and carbon emissions in developing countries. Through simulation tools, the proposed architecture was evaluated, demonstrating its cost-effectiveness and energy efficiency. Another study introduced a dynamic resource allocation algorithm for cloud data centers in developing nations, aiming to reduce energy usage in idle servers by allocating resources based on workload demand. Simulation results indicated improved energy efficiency and reduced energy consumption compared to static resource allocation methods. [6]

III. Research Methodology

A. Problem Formulation

With the rise of cloud computing services, the demand for data centers and parallel computing has increased significantly. However, operating large geographically distributed data centers consumes a substantial amount of energy, resulting in high operational costs. Energy consumption also necessitates expensive cooling systems, which can negatively impact equipment dependability and might breach client Operational Quality commitments.

In the beginning, energy-saving technologies aimed to improve the power consumption of data center equipment. DVFS and DPM technologies have been substantially researched and implemented.

However, the effectiveness of these procedures is limited without central coordination and energy-aware workload scheduling. Energy-aware scheduling aims to concentrate workloads on a minimal set of computing resources to optimize power consumption.

B. *Methodology*

The experiments take place in an energy-conscious storage center with Tier II, Tier III, and Tier III super speed designs. The quantity of computational units is fixed at 1536 for these architectures, whereas connection toggle layout and connections differ. The 2T architecture lacks the accumulation switches and base switches link to the access channel network through single GE lines. In contrast, the triple-tier high-speed design enhances the 3-tier infrastructure by offering more speed in the central and accumulation components of the connection. First and fourth connection and second and third connection connects in the triple-tier high-speed design architecture have ten times the bandwidth of the 3-tier architecture, corresponding to 100 Gigabit Ethernet and 10 Gigabit Ethernet, respectively. The workload generation events follow an exponential distribution, and the size of the workloads depends on the scope of the work. The computational and transmission of information requirements of the workloads are proportional, with different ratios for different workload types (CIW, DIW, and balanced). [6] [8]

C. *Data Center Architecture*

National data center of Bangladesh have over 100,000 servers, with most communications happening internally. This creates a challenge in designing network architecture and protocols. Because of both physical and financial constraints, the traditional structured communication architecture becomes an obstacle. 10 Gigabit Ethernet components have defined the evolution of data center architecture, but their high cost and capacity may not be necessary for connecting individual servers. Despite this, 10 GE transceivers are becoming more prevalent in storage facilities, metro area networks, and backbone connections.

D. *Two-tier data center architectures*

This article describes a two-tier network architecture used in data centers, where tier-one consists of computing servers arranged in racks and 2T uses L3 switches for utilizing full-mesh connection 10 Gigabit Ethernet links. Traffic equalization is accomplished through the usage of

ECMP routing of TCP and UDP packets. Compact data centers can benefit from the two-tier designs, with up to 5500 nodes supported depending on the access network switches used. The total bandwidth on the network supplied per CPU server is determined by the quantity of core routers and the ability of core connections. [1]

E. Three-tier data center architectures

The most common data center architecture today is the three-tier architecture, consisting of Access, Aggregation, and Core layers. The accessibility of the integration tier permits an expansion in server units yet maintains the access network's Layer-2 switches affordable. A typical three-tier architecture includes eight core switches to implement an 8-way Equal-cost multi-path routing, with 10 Giga-bit Ethernet Line Aggregation Groups allowing network clients to address multiple links and ports with a single MAC address. [7]

F. Three-tier high speed data center architectures

The goal of three-tier high-speed data center systems is to maximize the number of nodes as well as the capability of the primary and aggregation connections (see Figure 1). These networks often serve as bottlenecks, limiting the maximum number of nodes or the per-node bandwidth. The number of core switches can be lowered by using 100 Gigabit Ethernet cables among the core and aggregation switches. This approach overcomes the limitations of Link Aggregation Group (LAG)

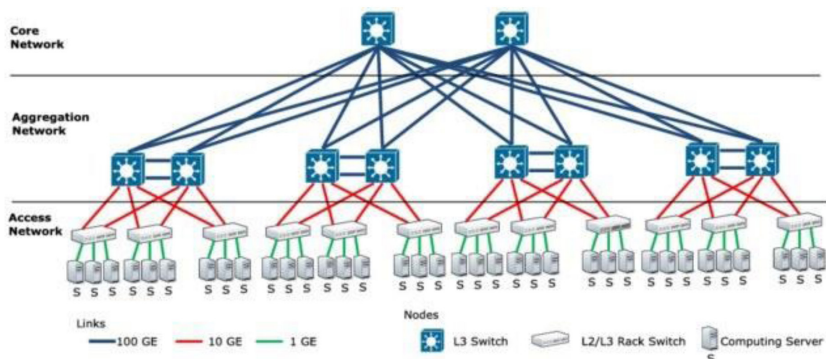


Figure 1

Three-tier high-speed data center architecture

technology, reduces cabling requirements, and significantly increases the maximum size of the data center within physical limitations. The reduced number of Equal-Cost Multipath paths enhances network efficiency and adaptability. [2]

IV. Simulation of Data Center

In data centers, a significant portion of energy is used for interconnection links, network equipment, power distribution, and refrigeration mechanisms. One category of power usage involves processing power, communication vitality, and infrastructure-related energy. The productive storage facility is determined by the attained efficiency each watt, measured by metrics like Power Usage Effectiveness (PUE) and Data Center Infrastructure Efficiency (DCiE). These metrics indicate the proportion of consumed energy effectively utilized by computational algorithms [11].

A. Structure of the simulator

An addition to the NS2 system model is GreenCloud specifically designed for studying cloud computing environments. It provides users with a detailed and precise modeling of energy consumption in data centers, including servers, switches, and links. GreenCloud also allows for in-depth analysis of workload distributions. Notably, it emphasizes packet-level simulations of data center communications, offering fine-grained control that is unique among cloud computing simulation environments. The GreenCloud extension aligns its structure with the three-tier data center architecture.

B. Servers

In GreenCloud, servers in data centers have preset processing power limits and various task-scheduling mechanisms. Power consumption depends on server state and CPU utilization, with idle servers using about 66 percent of energy compared to fully loaded configurations. Dynamic Voltage/Frequency Scaling (DVFS) is a power management option that balances performance and energy consumption. The power model considers both fixed and frequency-dependent CPU power. Scheduling in GreenCloud aims to capture the effects of DVFS and Dynamic Power Management (DPM) techniques, optimizing server load and operating frequency. [3] [9] When taking into account the fact that the system's

equipment like the bus, RAM, and drives are unaffected by the central processing unit (CPU) frequency, the electrical power usage of a typical system in GreenCloud can be described as follows.

schemes, including Dynamic Voltage Scaling (DVS) only, Dynamic Network Scaling (DNS) only, and a combination of DVS and DNS.

D. Workloads

Workloads in cloud computing encompass a wide range of user services like instant messaging, community building, and material distribution. Tasks in clustering consist of jobs, which can be divided into dependent or independent tasks. Grid computing often faces a higher number of jobs than available computing resources. While the primary objective is to minimize overall computation time, individual

$$P = P_{\text{fixed}} + P_f \cdot f^3 \quad (1)$$

P_{fixed} represents the amount of energy used that remains constant regardless of the The running frequency is f , and P_f is an indication of the bandwidth-dependent CPU energy consumption.. The power curve is based on An average system powered by an Intel Xeon chip would use 301 W of vitality, with 171 W set apart for different components and 130 W reserved for maximum processing horsepower. The impacts of DVFS and DPM methods are maximized in GreenCloud planning by taking into account the server's traffic level and service periodicity.

C. Switches and Links

Switches and links are essential components of the interconnection fabric in data centers, enabling timely delivery of workloads to computing servers. Different cabling solutions are required based on bandwidth, link characteristics, and transmission quality. Twisted pair cables are An ordinary Ethernet network element that can handle Gigabit Ethernet connections up to 100 meters with electricity. consumption of approximately 0.4W for transceivers. Optical multi- mode fibers are preferred for 10 Gigabit Ethernet links, allowing transmissions up to 300 meters with a power consumption of 1W. However, multi-mode fibers are more expensive than twisted pair cables, leading to a trend of limiting the use of 10 GE connections to compilation and core infrastructures to manage infrastructure costs within the data center budget.[2] The number of switches in a data center depends on the chosen architecture, but the most common switch is the Top-of-Rack switch, typically located at the

top of each rack unit to minimize cable clutter and heat generation. Gigabit or 10 Gigabit rates can be utilized by ToR converters, with gigabit rates being more common due to cost considerations and limited capacity in aggregation and core networks.

Initial suggestions for connectivity energy reduction networks relied on Dynamic Voltage Scaling links, where each switch port had a control element that could adjust the transmission rate based on traffic patterns and link utilization. However, DVS links' energy use is constrained since only some of the energy used grows straight with connection speed. Standard link transmission rates for gigabit links are restricted to 10 Megabits per second, 100 Megabits per second, and 1 gigabit per second options. The energy consumption of Research show that a switch and associated receivers can be specified. [4]

$$P_{switch} = P_{chassis} + n_{linecards} + P_{linecard} + \sum_{i=0}^r n_{ports} \quad (2)$$

The power consumed by a switch can be divided into three components: $P_{chassis}$, which represents the device hardware's energy use; $P_{linecard}$, which corresponds to the amount of electricity used by a running broadband connection board; and P_r , which represents the amount of energy used by an interface when it runs at a particular speed. Among these components, only P_r is dependent on the link rate, while $P_{chassis}$ and $P_{linecard}$ remain constant during the switch's operation. To conserve energy, it is possible to turn off or put the switch hardware into sleep mode, thus avoiding $P_{chassis}$ and $P_{linecard}$. The GreenCloud simulator incorporates an energy model for switches and links, using predefined power consumption values for each component. The simulator implements various power-saving jobs usually don't have strict deadlines. Cloud computing, on the other hand, involves incoming requests for applications such as web browsing, instant messaging, and content delivery. In cloud computing, jobs are often independent and less computationally intensive, but they have strict completion deadlines outlined in Service Level Agreements (SLAs). Three kinds of jobs are defined that encompass an extensive variety of cloud applications. Each load in GreenCloud is made up of two parts: compute and networking. [10] The computing component specifies the amount of computation required to meet a deadline, while the communication component determines the size and frequency of data transfers within and outside the data center.

V. Results And Discussion

Energy-aware server room models for two-tier, three-tier, and three-tier high-speed infrastructures were carried out. The quantity of computational nodes was fixed at 1430 for fair comparison, while the network switches varied. Unlike other architectures, tier two does not have aggregation switches. Core switches in tier two are directly connected to the access network using single Gigabit Ethernet connections, and interconnected with 10 Gigabit Ethernet links. Tier three high speed improves on tier three by providing more bandwidth in the core and aggregation parts, with first and second connection and second and third links having ten times the bandwidth of tier three. Each of the links have a transmission delay of 10 ns.

Table I
Parameters for simulating data center

Parameter	Tier Two	Tier Three	Three Tier High-speed DC
Core Nodes	16	8	2
Aggregation	0	8	4
Switch	512	512	512
Servers	1536	1536	1536

Workloads in the system follow an exponential distribution and vary in size. The average workload size and the computational requirements vary according to the work type. The interaction channel and data transmission ratio for CIW tasks is 1/10, while for DIW tasks, it is reversed. Balanced workloads distribute the load evenly across computing servers and data center networks. A green scheduler is used to schedule workloads, aiming to minimize the number of computing servers utilized. To handle DIW workloads, the scheduler monitors network switch buffer occupancy and avoids congested routes, even if they have servers capable of meeting computational requirements. Idle servers enter sleep mode, and underutilized servers reduce the supply voltage, with a 100 ms transition time for power state changes. The highest load is handled by roughly a third of the machines in the data center, while the rest, or two-thirds, can be shut off using the DNS approach. Among the approximately 50 servers with a declining load, some are under-utilized and can benefit from the DVFS technique. The peak energy consumption of a server is 301W, with 130W allocated to the CPU and 171W consumed by other

Table II
Power utilization of different types of data center

Parameter	Two tier	Three Tier	Three tier High speed DC
Data center	432	513	528
Servers	341	371	371
Switch	146	153	159
Core	52	26	53
Aggression	0	61	25
Access	75	55	65

devices. The minimum idle server consumption is 198W, which includes 27W for the operating system (See table I).

The power consumption of switches remains relatively constant across different transmission rates, with the majority of power used by their chassis and line cards rather than port transceivers. The consumption of core and The number of aggregation ports vary according to the data center architecture. These switches utilize a few kW in the Tier three topology with 10G paths, but tens of kilowatts in the tier-three high-speed topology, resulting in quicker switches. Modeling outcomes for three different data center architectures, assuming a 30% average load, highlight the energy-related costs and identify areas where energy management strategies can be most effective. During an hour of operation, the data center consumes an average of approximately 432 kWh. Computing servers account for roughly 70% of overall energy usage, with transport lines and switches accounting for the other 30%. A summary of switch intake is provided below: Core switches make up 17%, aggregation switches make up 34%, and route switches make up 50% (see Table II). After reducing computing server utilization, reducing the electrical burden of access switches is going to have the largest impact. The combined energy consumption of core and aggregation switches is 0.2% of overall energy use. Yet, in order to maintain network efficiency, load distribution, and communication dependability, core and aggregates switches must be maintained consistently operational, potentially implementing distributed communication rate reduction.

The power consumption of different data center architectures is influenced by the data center network. In comparison to the 2T architecture, the 3T architecture requires an additional 25 kW for the aggregation layer, allowing scalability beyond 10,000 nodes. The 3Ths architecture has fewer

Table III
Analysis of energy-saving measures

Parameter	No Energy Saving	DVFS	DNS	DNS+DVFS
Data center	502	86	47	34
Servers	352	99	33	34
Switch	155	92	33	33
Energy Costs	\$446	\$455	\$173	\$147

core and aggregation switches but consumes more energy per switch due to the availability of 100 G links. Comparing the energy consumption impact, the study evaluates the effects of DVFS, DNS, and a combination of both schemes on computing servers and networking equipment. Balanced tasks are considered, evenly loading at an overall load of 30%, and compute servers and the connectivity of interconnections are used (see Table III).

The DVFS method alone reduces server power usage to 96% of the normal level, which is accomplished mostly by lowering CPU voltage on underused servers (See Figure 2). However, DVFS has little usefulness for switches, with transmission rate variations affecting only 3% to 15% of their energy. The DNS method, on the other hand, demonstrates substantial effectiveness across both servers and switches, as the amount of energy they use is not affected by working frequency. Coupling the DNS protocol with a data center controller that optimizes server unloading is critical for optimal outcomes. Annual data center energy

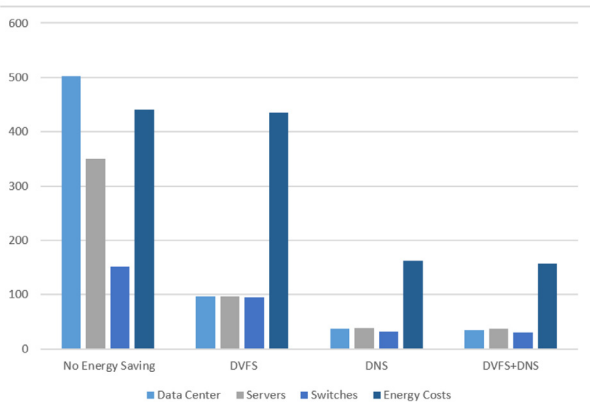


Figure 2
Comparison of energy efficient scheme

expenses are estimated at the bottom of the table. The initial energy expenditure of \$441,000 can be lowered by one-third by deploying a mix of DVFS and DNS methods, totaling \$157,000.

The curves depict the energy consumption of the entire data center, as well as the servers and switches, for balanced workloads. The DVFS scheme is minimally affected by server load and has limited sensitivity to switch load. In contrast, the DNS scheme precisely adapts power consumption of both servers and switches according to load variation. The reported results are averaged over 20 runs, considering the impact of workload arrival variations on server and switch requirements. The maximum variance of the confidence intervals is less than 0.2% for server energy consumption and less than 0.1% for network switch energy consumption.

VI. Conclusion and future work

GreenCloud, a modeling platform for energy-conscious cloud technology servers, is developed to capture energy consumption details of data center components and packet-level communication patterns. Simulation results for two-tier, three-tier, and three-tier high-speed architectures showcase the effectiveness of power management schemes like voltage scaling and dynamic shutdown on both computing and networking components. Future work aims to expand the simulator by incorporating approaches for organizing storage networks and improving energy simulations for virtual components.

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