Exploration of Energy-Efficient Data Center Design for Diverse Cloud Environments

Sanju Rajan[1*], Linda Joseph[2]
[1*]Research Scholar, Hindustan Institute of Technology and Science, Chennai, Tamilnadu, India.
[2]Associate Professor, Hindustan Institute of Technology and Science, Chennai, Tamilnadu, India.
[1*]linda24in@gmail.com, [2]sanjurajan6@gmail.com

Article Info
Page Number: 1055-1068
Publication Issue:
Vol. 71 No. 3s (2022)

Article History
Article Received: 22 April 2022
Revised: 10 May 2022
Accepted: 15 June 2022
Publication: 19 July 2022

Abstract
Cloud computing enables you to access your information from anywhere at any time. The model enables on demand network of share pool of configured computing resources. With the expansion of computer and mobile users' accessibility and storage has become the main concern. In dispensed systems, such as cloud computing, heterogeneity is becoming increasingly popular. Hardware is becoming more specialised and diverse due to requirements for high performing computers. Studies show thorough examinations of schedules executed in cloud computing settings. This also makes it imperative to optimize resources while maximizing performance of systems. The majority of this progressive analysis of energy potency has mostly focused on the process component improvement. The results of simulations for two-grade, three-grade, and three-grade high-speed data center designs demonstrate that the simulator is capable of managing power of computing and networking components by scaling of voltages or frequencies and shutting down systems. In order to illustrate an energy-aware cloud computing data centre simulation environment, this paper introduces a model environment dubbed GreenCloud Simulator for contemporary energy learning of cloud computing data centres in realistic configurations.
Keywords:Cloud computing, resource management, energy efficiency, scheduling, greencloud simulation.

1. Introduction

With the rise of the internet, computers, and data centers, a significant quantity of power is being utilized. Almost every sector today, including healthcare, vehicles, and finance, is reliant on IT, resulting in a great quantity of energy consumption and increasing costs, which is why Green computing was born. Green computing's major goal is to ensure that all computer devices are used in an efficient and environmentally friendly manner, including device design and production. It also tries to recycle and reuse electronic gadgets. Cloud Computing was defined by NIST (National Institute of Standards and Technology) as models for providing complete, effective, on-request network accesses to shared pools of configurable registering assets that can be quickly provisioned and delivered with little administrative efforts or professional organisation association [1]. Cloud computing are methods of offering end users with computers, data accesses, and storages without the awareness of locations. The efficiencies of resources are enhanced by the usage off their combined power and address large-scale computational challenges [2].

Administering cloud's physical resources including servers, routers, switches, and power and cooling systems are responsibilities of hardware layers which are proliferated by data centres [3]. Data centres are being used more frequently to provide computing resources.With the expansion in computer capacity, data center costs and operating expenses have surged. The energy devoured by data innovation (IT) gear, which incorporates energy needed by figuring workers just as server farm network equipment used for interconnection, represents around 40% of the aggregate.[4].
In fact, communication links and its elements utilize around one-third of overall IT energies, while computing servers consume the balance. Other components that affect data centre's energy usages include electricity and cooling distribution systems which account for 45 and 15 percent of total energies [5]. Many studies have examined on lowering energy consumptions of cloud computing infrastructures based on their escalating energy needs and growth. Academic studies dealing with cloud infrastructure face challenges due to their complex environments. Cloud simulation software are one way of handling these obstacles. Hence, the main purpose of this study is to evaluate GreenCloud and CloudSim, two of the most popular cloud modelling simulations [6].

2. Related Work/ Background

The most common data center architecture is a three-tier tree of hosts and switches. The main level is core at the top, subsequently the aggregation level, which deals with routing, and the access level, which is pool of computing servers (or hosts) [7] Figure 1. There was no aggregation tier in early data centers, thus they employed two-tier structures. However, depending on the counts of active switches and bandwidth needs of hosts, data centres, generally support up to 5,000 hosts. Three tiered designs in data centres are capable of handling 1,00,000 hosts (servers) and necessarily maintain slab-2 switches for network accesses [8]. Despite the market's availability of 10 Gigabit Ethernet (GE) recipients, a professional architecture connects each calculation server (which is arranged in a rack) to the others utilising 1 GE links. This is the reason why 10 GE transceivers would be uneconomical in terms of cost and space as they might connect more computers than was necessary. Frame association in data centres is accomplished using low-cost Top-of-Rack (ToR) switches. Two 10 GE uplinks and 48 GE connections from the ToR switch are used to connect the compute servers in a rack.The difference between a switch's downlink and uplink capacity determines its oversubscription ratio, which in the example above is 48/20 = 2.4:1. As a result, each of the individual servers will only have 416 Mb/s available out of their 1 GE lines when they are fully loaded.
At the top of ranking, racks are organised into modules which include many aggregation switches which connect modules. These aggregation switches have oversubscription ratios of 1.5:1, resulting in reducing maximum bandwidths available to single servers (277 Mb/s). Multi-path routing called ECMP (Equal Cost Multi-Path) routing, divides bandwidths across core and aggregated networks. ECMP approaches create hash functions on receiving packet headers for providing load balances in flows [9]. The highest channel count of ECMP in three tiered systems limit core switches counts to eight. The bandwidth that can be provided to the collection switches is similarly limited by this restriction. This restriction will be

eliminated with the regulation of 100 GE links' (commercial) accessibility, which took effect in June 2010 [10].

Data centres exhaust lot of energies while running their computing servers where power used by servers depend on the CPU time consumed. Two-thirds of server peak loads need to be maintained for idle memory, storage, and I/O usages. As the amount of CPU load increases, the remaining one-third varies almost linearly [11].For lowering energy usage in computing servers, there are two basic ways: (a) DVFS [12] and (b) DPM [13].

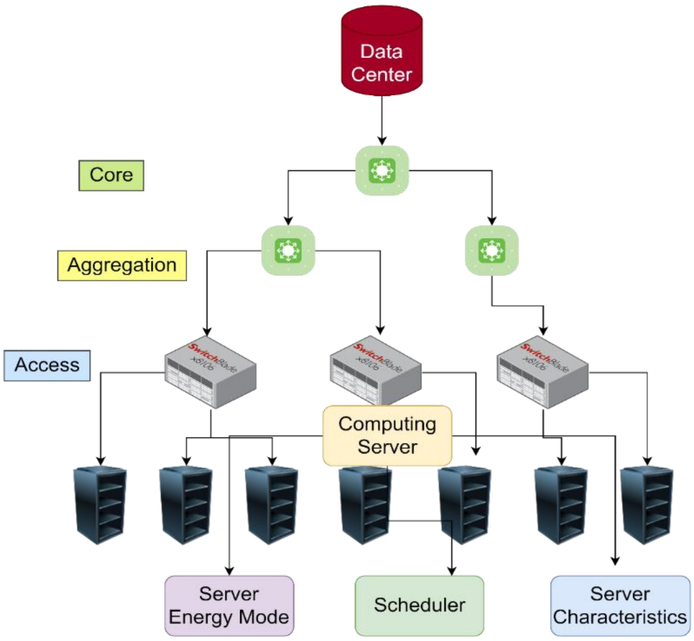

Figure 1; The Architecture with Core, Aggregation and Access Layer that Linked with Data Center

Switches serve as the foundation of the interconnection network, which routes job requests to the computing servers for processing.The amount of energy used by a switch is determined by the type of switch: (a) sort of switch, (b) total ports, (c) port communication ratio, and (d) engaged transmitting cables. The following equation can be used to generalize the energy exhausted by a switch [14]:

$$P_{switch} = P_{chasis} + n_{linecards} * P_{linecard} + \sum_{i=0}^{R} n_{ports} * P_i$$

where P_{chasis} represents switch hardware's basic power usage, $P_{linecard}$ stands for live linecard power consumptions, and P_i represents operational port's (transmitter) power usage running at rate i. Advantages of rate adaptive methods get constrained when overall energy consumptions of switch transceivers account for only 3–15% of their total energy consumptions [15]. $P_{chassis}$ and $P_{linecard}$don't scale with circulation rate and can only be averted if the switch hardware is off (as long as the switch doesn't have to process any traffic). Of course, not all switches can be suspended dynamically. To service enormous switching capacity, each core switch consumes a significant amount of energy.

Due to their position within the communication fabric and appropriate ECMP rerouting capabilities, the core network switches should always be operating at their maximum transmission speeds. The aggregation switches, on the other hand, serve modules that can be turned off when the module racks are not in use. Given that most data centers are only using about 30% of their compute capacity on average [16], turning down unused aggregation switches is a no-brainer. However, such an operation must be carried out with caution, taking into account potential swings in job arrival rates. To account for possible data center load variation, are generally sufficient to keep some computing server's stationary on highest of the necessary computing servers [11].

3. System Model/Scheduling Algorithm

In cloud computing, incoming requests are often created for online browsing, instant messaging, and a variety of content delivery services [17,18]. The jobs are more self-contained and less computationally hard, but they must be completed by the SLA deadline. The majority of such requests can be divided into three types based on the amount of computing and communications they necessitate:

CIWs - High-Performance Computing (HPC) programs are designed to solve complex computational issues. CIWs spend a loads of CPU assets yet to yield basically no data contributes in the data center's community network. The CIW endurable scheduling approach should focus the observation on the server power utilization traces, seeking to consolidate workloads amongst few servers as feasible and routing traffic over as few routes as possible. When there is little quantity of data that needs to be transmitted, network bottlenecks are a remote possibility. Additionally, by putting bulk of switches in sleep modes, data centre networks exhaust lesser energies.

DIWs - impose essentially little load on computational servers, but necessitate large data transfers DIWs are designed to represent applications such as video file sharing, in which a simple consumer request emerges as a video sliding system. As a result, interconnected network of data centres become bottlenecks for DIWs instead of higher processing powers. Continuous feedbacks between network components (switches) and main job schedulers would be implemented in real time where schedulers will distribute workloads based on feedbacks, taking into account present congestion levels of communication connections. Even if a server's CPU capacity allows it to handle the workload, it will avoid delivering it through congested networks. The data centre network's traffic will be balanced, and the length of time on average spent transferring tasks between core switches and servers will be minimized.

BWs - seeks to display applications that combine data transport and computation. BWs load servers and communication connections proportionately. With these workloads, the average stack on the servers corresponds to the average load on the data centre network. GIS applications, for example, can be modelled using BWs because they demand both huge graphical data transfers and significant computation. BW scheduling should take into account both the demand on the machines and the load on the association network.

In data centers, using an association fabric constitutes of operating different types of traffic (SAN, LAN, or IPC) on a single Ethernet-based broadcasting. Ethernet equipment is reasonable, simple to place, and administer. Furthermore, Ethernet gear is less effective and has limited buffering capacity. The main causes of network congestion are small buffers and a combination of high-bandwidth traffic. Either data center switches possibly congested in one of two the uplink or downlink indications, or both.

Distinct ingress link abilities exceed individual migration link abilities, causing congestion in the network direction. The primary causes of bandwidth mismatches in uplink instructions are oversubscription factors, which erupt when aggregate capacities of server ports exceeds aggregate uplink capacities of switches.

Figure 2 the root problem is because it is significantly more efficient to split data-intensive jobs among differing computer servers so that tasks do not divide up common communication scheme. To take advantage of the three-tiered design geographical division, jobs must be assigned to the computer in ratio to their communication requirements. Other jobs running in data centres can interface with tasks that create constant bit-streams aimed at end users like video sharing services. However, such methods go against energy-efficient schedules which aim concentrate on all active operations executing on servers while using least amounts of communication resources.

The subsequent section details on unified scheduling measures for managing trade-offs between energy efficiencies, data centre network congestions, and individual task performances. By choosing computing resources for task executions based on job levels and communications of data centre components, the approach reduces data center's overall energy consumptions. The recommended technique was evaluated with its application on GreenCloud simulator [19] where the simulator captured data centre communication interactions at packet levels. The simulations were network simulator add-ons that enabled genuine usages of TCP/IP operations in a variety of network configurations [20].

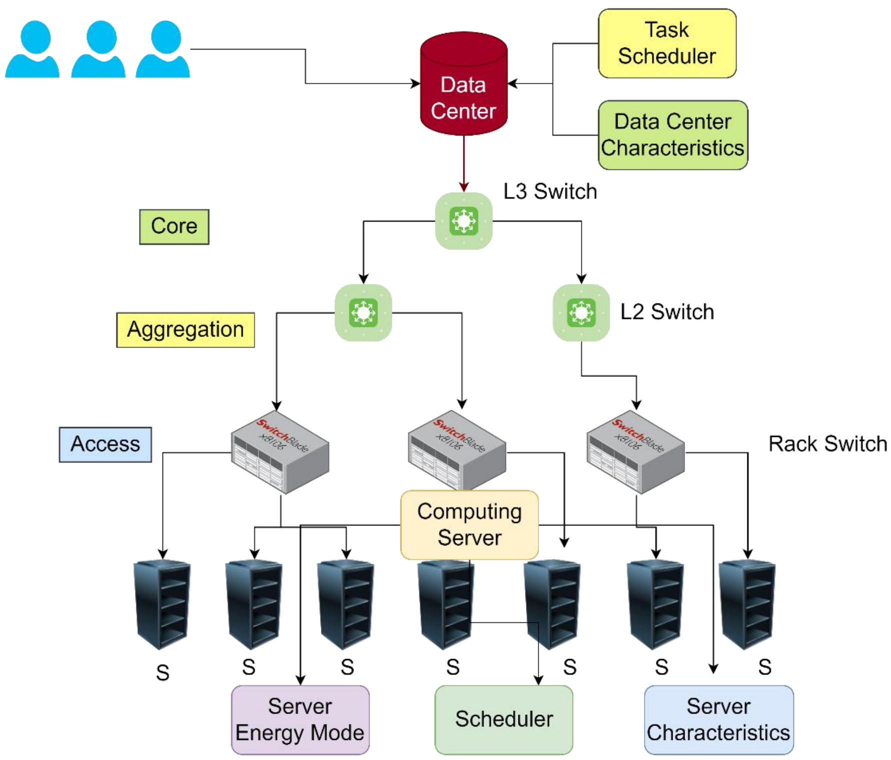

Figure 2; Data Management through a GreenCloudArchitecture with Computing Server

Users of GreenCloud were able to precisely estimate energy usages of various data centre components, including servers, switches, and communication cables. Additionally, GreenCloud offered thorough evaluations of workload allocations. Significant emphasis was paid to packet-level simulations of transmission in data centre architectures as they look after the best grain control and are not feasible in each and every cloud computing simulation region. DVFS and DPM methods are examples of energy-efficient optimization strategies that have been implemented [12]. The GreenCloud simulator's simulated three-tier data centre design is projected onto Figure 2. Computing servers employ a single core processing paradigm, have their own memory and disc storage, and can adhere to a variety of work scheduling criteria. Their transforming power is measured in MIPS (million instructions per second) or FLOPS (floating point operations per second).The communication fabric for task distribution is provided by network switches and cables. Different kind of loads in data center is displayed by performing the simulation using Core i3 and 4 GB ram on Linux platform [21]- [31].

The VM scheduling challenge involves arranging virtual machines on physical resources in data centers while adhering to constraints in order to optimize the objective function. As a result, the scheduler's ultimate purpose is to identify when and where (resource) the VMs should be deployed in order to successfully execute the operation. The number of servers, topology, users, and data center components are all initialized from the Figure 2. The task of each algorithm is to distribute resources for the execution of virtual machines that hold jobs. For processing the jobs held by the virtual machines, the user's priority and the QoS criteria mentioned in the SLA have been taken into account. The vm number of virtual machines has been allocated the "n" number of indivisible unit of jobs. For execution, these virtual machines must be scheduled with the necessary physical resources. The following steps need to be followed for the processing the results.

Algorithm of VM Scheduling

VM scheduling
Input: Number of servers, topology, user.
Outputs: Energy, computing time, and memory are the outputs.
Step 1: Initialization of
Users, servers, and data centre components.
Step 2: Setting parameters of
Task, aggregation switch, core switch, and nonlinear power model.
Step 3: Execution of Schedulers in
Random, Green, Round Robin, HEROS, RandDENS, and BestDENS
Step 4: Reports on data centre loads
each server's load
Personal VM load
a lot of separate connections
Step 5: Display total amount of energy used
servers' energy
A core switch's energy

Switches for aggregating energy Power switches for access

4. Results and Discussion

Table I and Figure 1 display the results of full-scale heterogeneous summary. The table II gives the parameter for the findings that were achieved. Generally speaking, the outcomes in this situation are the same as those in the small heterogeneous scenario. These schedulers, Random, ranDENS, and RoundRobin, use a lot of energy. As a result, they forbid servers from entering sleep mode and respond more slowly than others. The Green, bestDENS, and HEROS algorithms are the least energy-intensive ones. Successfully, the HEROS scheduler used 47% fewer servers' energy than the Green scheduler in Figure 4. For energy usage, the bestDENS values are more in line with the Green outcomes..

Table 1. Full Scale Heterogeneous Results

Energy	Green	HEROS	ranDENS	Random	RoundRobin	bestDENS
Switch Energy (Core)	51.4	51.4	51.4	51.4	51.4	51.4
Switch Energy (agg.)	102.8	102.8	102.8	102.8	102.8	102.8
Switch Energy (access)	9.1	9.1	9.1	9.1	9.1	9.1
Sever Energy	138.6	142.6	307.1	308.5	317.7	138.6
Energy Summary	301.9	305.9	470.4	471.8	481	301.9

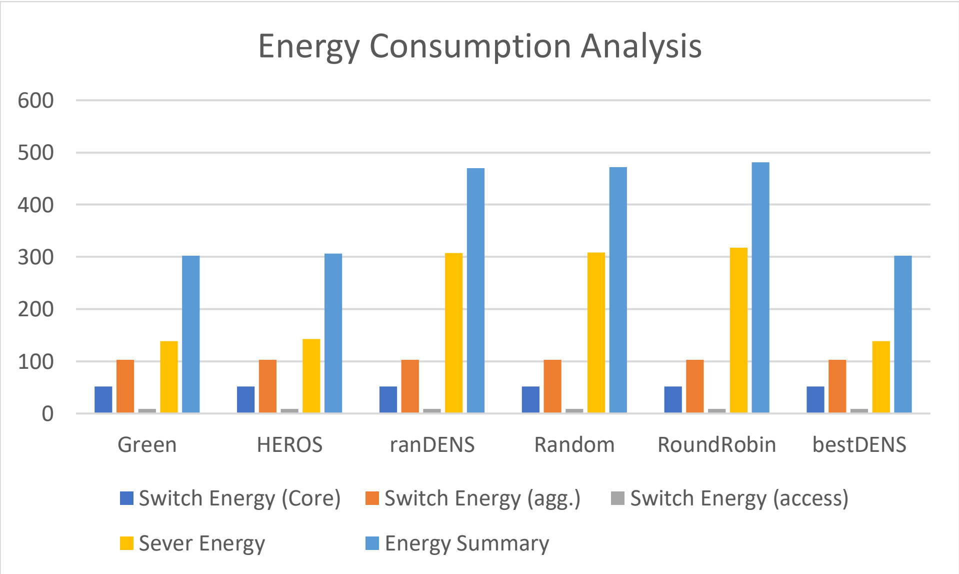

Figure 3; Comparison Bar Chart of Server Energy Consumption over various Approaches

Table 2. Three Tier Configurations

Configuration	Small
Core Switches	1
Aggregation Switches	2
Access Switches	3

Total Servers	144
User	1
Power mode of server	DVFS DNS
Power mode of switches	DVFS
Total tasks	32689
Datacenter load	26.0%

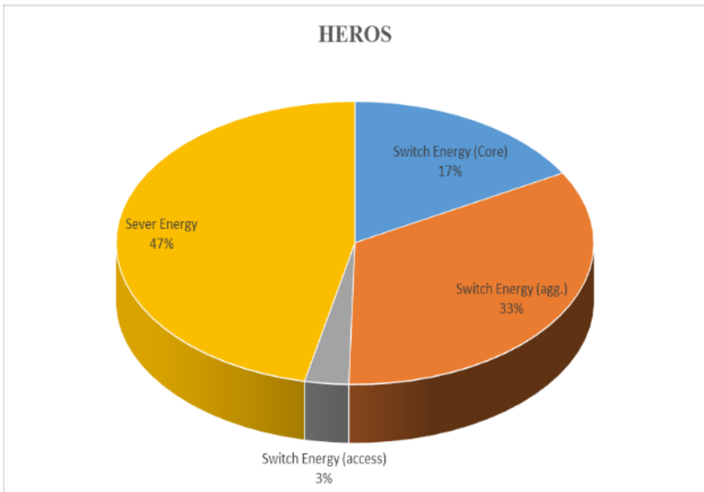

Figure 4; Pie Chart Comparison of HEROS Energy Expense

We provide an energy-conscious data centre modelling framework for cloud computing. The simulator is intended to record details of the energy consumption of data centre components (servers, switches, and connections), as well as packet-level communication patterns in realistic setups, in addition to workload distribution. The simulator can effectively implement power management methods such voltage scaling, frequency scaling, and dynamic shutdown on computing and networking components, as shown by the simulation results for two-tier, three-tier, and three-tier high-speed data centre architectures.

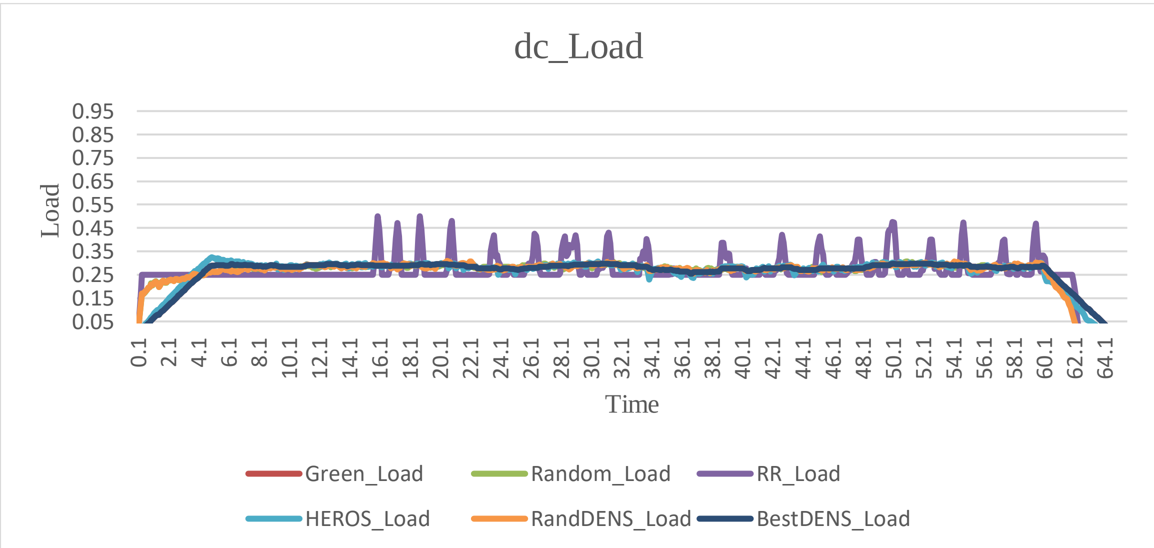

Figure 5; Datacenter Load

The main goals of common energy-conscious scheduling techniques are to (a) concentrate the workload on a limited number of computing resources and (b) increase the number of resources that can be put to sleep. A development of Ns2, GreenCloud is a packet-level network emulator. In a previously unheard-of manner, GreenCloud collects, aggregates, and makes information on the energy required by data centre computing and networking components available to the public.

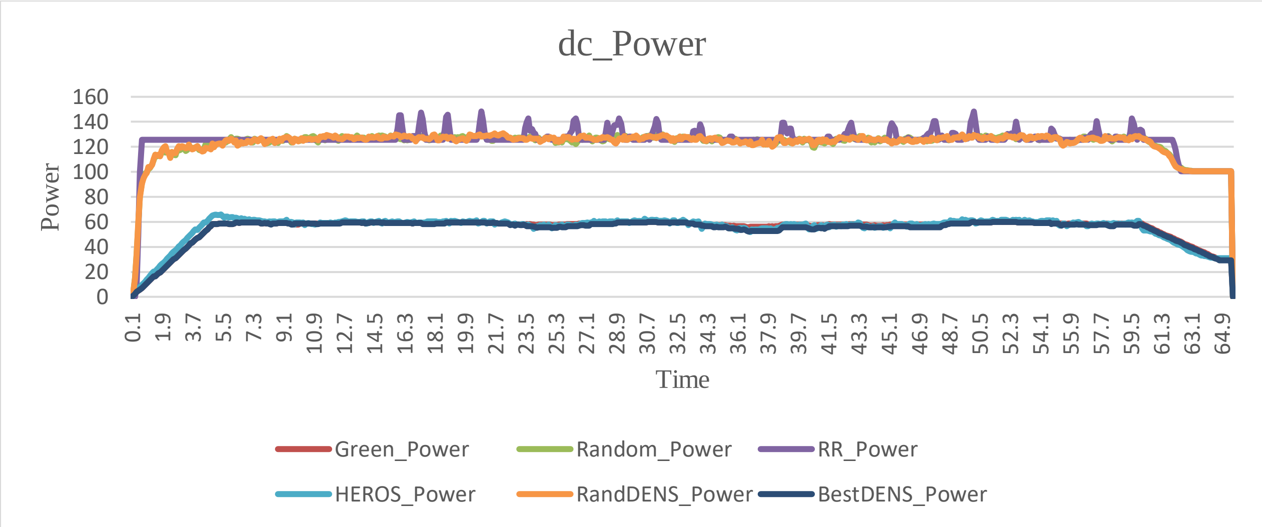

Figure 6; Datacenter Power

Customers may get a fine-grained model of the energy used by servers, switches, and networks in data centres thanks to GreenCloud. Additionally, GreenCloud offers a thorough examination of workload allocations. Additionally, particular focus is placed on the packet-level simulations of communications in the data centre architecture, which provide the finest-grain control and are absent from all cloud computing simulation environments. Accurately documenting communication patterns of both present and future data centre systems is given particular priority.

Only a portion of the data center's electricity is provided directly to the computer servers. The functioning of interconnection lines and network equipment consumes a significant amount of energy. The remainder of the power is wasted in the distribution network, lost as heat energy, and used by air-conditioning units. In light of the aforementioned, we distinguish three energy consumption components in GreenCloud: computer energy, communication energy, and energy related to the physical infrastructure of a data centre. GreenCloud has created energy models for every part of a data centre (computing servers, core and rack switches).

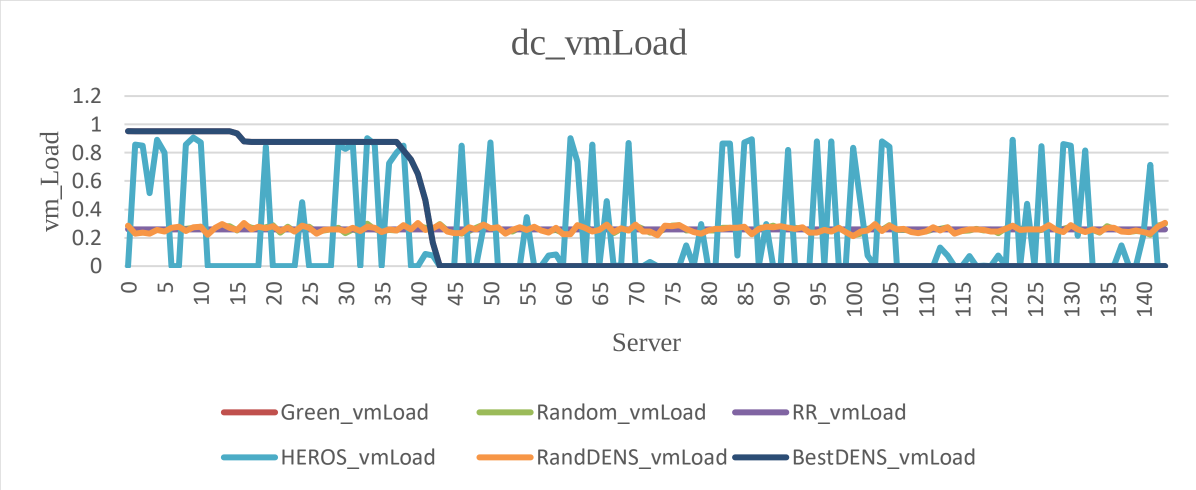

Figure 7; Datacenter Virtual Machine

Furthermore, energy models can work at the packet level because to the advantage in simulation resolution. This permits the energy consumption levels to be updated whenever a new packet leaves or arrives from the link, or when a new task execution begins or ends at the server.

Table 3. Energy Efficiency

Configuration	**Small**
Core Switches	1
Aggregation Switches	2
Access Switches	3
Total Servers	144
User	1
Simulation Time	65.6

Figure 5 compares and contrasts datacenter loads while using Green, Random, RR (Round Robin), HEROS, RandDENS, BestDENS. Figure 1 demonstrates datacenter load consumed by RR (Round Robin) is unsteady loads followed by RandDENS. HEROS, Green and BestDENS demonstrates a steady load distribution over the simulation time period. RR makes no attempt to avoid network congestion and arranges jobs on the smallest number of servers possible. As a result, as indicated in the network performance comparison, congestion arises at several switches. BestDENS has little more durability compared to HEROS and Green.

Figure 6 shows comparison of datacenter power utilization as for the required load and time. It shows that Random, RR (Round Robin) and RandDENS has higher power consumption. The other HEROS, Green and BestDENS remains economical in the power usage. Even from this BestDENS attains more optimised usage of power. In Figure 7, the allocation of vm to different servers available. Random, RR (Round Robin) and RandDENS has steady movement of vm until the last server. Green and BestDENS has high movement of vm until 40 server and then the allocation is zero. HEROS is the most volatile proportion of vm movements. All these components in datacenter contribute to significant energy saving model.

5. Conclusions

This paper, which combines network awareness with energy-efficient scheduling, emphasises the significance of communication fabric in data centre energy utilisation. The method takes into account a data center's energy usage, the effectiveness of each activity, and traffic needs. This methodology is especially important in data centers that conduct data-intensive activities that demand little CPU power but output large data streams for end-users. The algorithm that uses the least amount of energy is Green, bestDENS and HEROS. The HEROS scheduler successfully and when compared to the Green scheduler, it uses 47% less power on servers. The simulation results for the three-tier data centre architecture show algorithm working details and the algorithm's capacity to preserve the required degree of QoS for the end-user at the price of a slight increase in energy consumption. The hybridDENS algorithm has been suggested for further development to reduce server energy usage. The algorithm metric's design and specification are inextricably linked to the underlying data center architecture. It was the most often utilized three-tier architecture in this study.

References

1. Antony Rosewelt, L. and ArokiaRenjit, J. ‘A Content Recommendation System for Effective E-learning Using Embedded Feature Selection and Fuzzy DT Based CNN’. 1 Jan. 2020: 795 – 808
2. M.S. Mekala, A. Jolfaei, G. Srivastava, X. Zheng, A. Anvari-Moghaddam, P. Viswanathan, Resource offload consolidation based on deep-reinforcement learning approach in cyber-physical systems, IEEE Transactions on Emerging Topics in Computational Intelligence (2020).
3. W. Wei, R. Yang, H. Gu, W. Zhao, C. Chen, S. Wan, Multi-Objective Optimization for Resource Allocation in Vehicular Cloud Computing Networks, IEEE Transactions on Intelligent Transportation Systems. (2021).
4. L. Zuo, L. Shu, S. Dong, Y. Chen, L. Yan, A multi-objective hybrid cloud resource scheduling method based on deadline and cost constrains, IEEE Access 99 (2017) 1–13.
5. X. Gao, R. Liu, A. Kaushik, Hierarchical multi-agent optimization for resource allocation in cloud computing, IEEE Transactions on Parallel and Distributed Systems 32 (3) (2020) 692–707.
6. V. Ramasamy, S.T. Pillai, An effective HPSO-MGA optimization algorithm for dynamic resource allocation in cloud environment, Cluster Computing 23 (3) (2020) 1711–1724.
7. S. Goyal, S. Bhushan, Y. Kumar, M.R. Bhutta, M.F. Ijaz, Y. Son, An Optimized Framework for Energy-Resource Allocation in a Cloud Environment based on the Whale Optimization Algorithm, Sensors 21 (5) (2021) 1583.

8. L.S. Subhash, R. Udayakumar, Sunflower Whale Optimization Algorithm for Resource Allocation Strategy in Cloud Computing Platform, Wireless Personal Communications 116 (4) (2021) 3061–3080.
9. George Fernandez, I. and ArokiaRenjith, J. ‘Resource Allocation, Scheduling and Auto-scaling Algorithms for Enhancing the Performance of Cloud Using Grey Wolf Optimization and Fuzzy Rules’. 1 Jan. 2020 : 7449 – 7467.
10. G. Dhiman, M. Garg, A. Nagar, V. Kumar, M. Dehghani, A novel algorithm for global optimization: Rat swarm optimizer, Journal of Ambient Intelligence and Humanized Computing (2020) 1–26.
11. Jadeja, Y., & Modi, K. (2012, March). Cloud computing-concepts, architecture and challenges. In 2012 International Conference on Computing, Electronics and Electrical Technologies (ICCEET) (pp. 877-880). IEEE.
12. Joseph L and R. Mukesh, "To Detect Malware attacks for an Autonomic Self-Heal Approach of Virtual Machines in Cloud Computing," 2019 Fifth International Conference on Science Technology Engineering and Mathematics (ICONSTEM), 2019, pp. 220-231, doi: 10.1109/ICONSTEM.2019.8918909.
13. Joseph L and R. Mukesh, "Detection of Malware Attacks on Virtual Machines for a Self-Heal Approach in Cloud Computing using VM Snapshots," in Journal of Communications Software and Systems, vol. 14, no. 3, pp. 249-257, September 2018, doi: 10.24138/jcomss.v14i3.537
14. Joseph, L., Mukesh, R. Securing and Self recovery of Virtual Machines in cloud with an Autonomic Approach using Snapshots. Mobile NetwAppl 24, 1240–1248 (2019). https://doi.org/10.1007/s11036-019-01261-3
15. Kliazovich, D., Bouvry, P., & Khan, S. U. (2012). GreenCloud: a packet-level simulator of energy-aware cloud computing data centers. The Journal of Supercomputing, 62(3), 1263-1283.
16. Liu, J., Zhao, F., Liu, X., & He, W. (2009, June). Challenges towards elastic power management in internet data centers. In 2009 29th ieee international conference on distributed computing systems workshops (pp. 65-72). IEEE.
17. Mahadevan, P., Sharma, P., Banerjee, S., &Ranganathan, P. (2009, April). Energy aware network operations. In IEEE INFOCOM Workshops 2009 (pp. 1-6). IEEE.
18. F. Farahnakian, T. Pahikkala, P. Liljeberg, J. Plosila, N.T. Hieu, H. Tenhunen, Energy-aware vm consolidation in cloud data centers using utilisation prediction model, IEEE Trans. Cloud Comput. (2016).
19. Ramamoorthy, S., Ravikumar, G., SaravanaBalaji, B. et al. MCAMO: multi constraint aware multi-objective resource scheduling optimization technique for cloud infrastructure services. J Ambient Intell Human Comput 12, 5909–5916 (2021). https://doi.org/10.1007/s12652-020-02138-0
20. Pepsi M, B. B. ., V. . S, and A. . A. “Tree Based Boosting Algorithm to Tackle the Overfitting in Healthcare Data”. International Journal on Recent and Innovation Trends in Computing and Communication, vol. 10, no. 5, May 2022, pp. 41-47, doi:10.17762/ijritcc.v10i5.5552.

21. Ponmagal, R.S., Karthick, S., Dhiyanesh, B. et al. Optimized virtual network function provisioning technique for mobile edge cloud computing. J Ambient Intell Human Comput 12, 5807–5815 (2021). https://doi.org/10.1007/s12652-020-02122-8
22. S. Balakrishnan, J. Janet, K.N. Sivabalan, "Secure Data Sharing in a Cloud Environment by Using Biometric Leakage resilient Authenticated Key Exchange", Pak. J. Biotechnol. Vol. 15 (2) 293-297 (2018).
23. S. Balakrishnan, D.Deva, "Internal or External - Which Database Could Contribute More to Business Intelligence?" CSI Communications magazine, Vol. 42, issue 7, October 2018, pp. 24-25. ISSN: 0970-647X.
24. J. Janet, S. Balakrishnan and E. Murali, "Improved data transfer scheduling and optimization as a service in cloud," 2016 International Conference on Information Communication and Embedded Systems (ICICES), Chennai, 2016, pp. 1-3.doi: 10.1109/ICICES.2016.7518895.
25. Balakrishnan S., Janet J., Spandana S. "Extensibility of File Set over Encoded Cloud Data through Empowered Fine Grained Multi Keyword Search". In: DeivaSundari P., Dash S., Das S., Panigrahi B. (eds) Proceedings of 2nd International Conference on Intelligent Computing and Applications. Advances in Intelligent Systems and Computing, vol 467. 2017. Springer, Singapore.
26. J. Janet, S. Balakrishnan and K. Somasekhara, "Fountain code based cloud storage mechanism for optimal file retrieval delay," 2016 International Conference on Information Communication and Embedded Systems (ICICES), Chennai, 2016, pp. 1-4.doi: 10.1109/ICICES.2016.7518901.
27. J. Janet, S. Balakrishnan and E.R. Prasad, "Optimizing data movement within cloud environment using efficient compression techniques," 2016 International Conference on Information Communication and Embedded Systems (ICICES), Chennai, 2016, pp. 1-5.doi: 10.1109/ICICES.2016.7518896
28. M. Balasubramaniyan, M. Balasubramanian, S. Balakrishnan, "Data Movement Optimization In A Cloud Environment Using Capacity Optimization Technique", Jour of Adv Research in Dynamical & Control Systems. Vol. 10, 11-Special Issue, 2018, pp. 740- 743.
29. SruthiAnand, N.Susila, S.Balakrishnan, Challenges and Issues in Ensuring Safe Cloud Based Password Management to Enhance Security", International Journal of Pure and Applied Mathematics, Volume 119, No. 12, 2018, pp.1207-1215.
30. Dipon Kumar Ghosh, PrithwikaBanik, Dr. S. Balakrishnan (2018), "Review-Guppy: A Decision-Making Engine for Ecommerce Products Based on Sentiments of Consumer Reviews", International Journal of Pure and Applied Mathematics, Volume 119, No. 12, 2018, pp.1135-1141.
31. K. Aravind, J. Granty Regina Elwin, T. Sujatha and S. Balakrishnan, (2018), "A Novel And Efficient Mobile Cloud Service For Searching Encrypted Data", ARPN Journal of Engineering and Applied Sciences, Vol.13, No.16, pp. 4683- 4686, 2018.
32. M. Syed Shahul Hameed, Ravi Kumar Poluru, Chandra Prakash Lora, S. Balakrishnan, A Non-Invasive Check Alarm Towards Food Safety Against Scruples

Using Iot For The Produce, Nat. Volatiles &Essent. Oils, 2021; 8(4): 10734-10743 10734.

33. Arellano-Zubiate, J. ., J. . Izquierdo-Calongos, A. . Delgado, and E. L. . Huamaní. "Vehicle Anti-Theft Back-Up System Using RFID Implant Technology". International Journal on Recent and Innovation Trends in Computing and Communication, vol. 10, no. 5, May 2022, pp. 36-40, doi:10.17762/ijritcc.v10i5.5551.