Comparative study of energy efficiency techniques in cloud using CloudSim

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Abstract:

Virtualization is a vital part of cloud computing. Virtualisation helps optimize IT resources in a very ascendable manner. It disjoins the package from the hardware. It's characteristics of partitioning, isolation and encapsulation make it idyllic to be used in cloud computing. Virtualisation helps with providing additional computing power with less physical hardware. Energy potency offers higher system performance and is nice economically. By exploiting resources effectively, we will accomplish this. Attaining this can be a part of an overall theme for setting property. once we manage cloud resources better, assignment policies get along such that minimum resources are used for higher practicality.

Keywords:

Virtual Machines, Cloud management, Energy Efficiency, CloudSim, Scheduling algorithm, First Come First Serve (FCFS), Shortest Job First (SJF), Largest Job First (LJF).

I. Introduction

When we manage cloud resources better, assignment policies get along such that minimum resources are utilised for higher practicality. Any practicality is first allotted to a virtual machine that is then positioned on the foremost suited server host. If any server becomes burdened, a number of its virtual machines are reallocated to a replacement location. This method needs a hotspot detection mechanism together with techniques that choose the virtual machine(s) to migrate. within the Cloud, the Virtual Machine Monitor (VMM) arbitrates the access to the real physical resources so completely different operative systems in VMs will share the host infrastructure. Virtualisation first virtualises a task by distribution it to a VM (Workload Isolation) then permits many VMs to share a physical platform (Workload Consolidation) and if necessary, moves it to a different server to balance the load (Workload Migration).

Cloud computing is rising technology and next massive step within the evolution of virtual computing within the field of IT among previous couple of years. It provides the measurability, flexibility, on demand services and virtualization variety of services over the net to the user. because the range of users is increasing day-by-day in cloud setting, load levelling has been become a difficult downside for cloud service supplier. to beat this kind of downside, several algorithms are projected by investigator, however all the algorithms have their benefits and limitation. the main aim of load levelling is to utilize the cloud resource (combination of hardware and software) in such means so output and resource utilization sort of parameter ought to be maximum. Load levelling helps to execute the task in minimum time and increasing the performance of the system i.e., user will come back to response in shortest amount of your time. different challenges additionally exist in cloud setting like security, data loss, heterogeneousness and high communication delay. Load levelling is achieved in cloud setting in 2 steps: initial one is to distribute the task among the node, second is to watch the virtual machine and perform the load levelling operation mistreatment task migration or virtual machine migration approach. The aim of task programming is to form a schedule and assigned each task to node (virtual machine) for specific period of time

so all tasks are dead in minimum time span. Task programming is NP complete problem within the field of applied science as a result of range of task and length of task change terribly speedily in cloud setting. it's tough to calculate all attainable task-resource mapping in cloud setting and notice an best mapping isn't straightforward task. Therefore, we want an economical task programming algorithmic program which will distribute the task in effective manner so a smaller range of virtual machines ought to be in overladen or underneath loaded condition. when allocating the task to virtual machine, cloud task hardware starts to perform load levelling operation so task will be transfer from overladen virtual machine to underneath loaded virtual machine and every one virtual machine ought to stay in balance condition.

CloudSim may be a framework for modelling and simulation of cloud computing infrastructures and services. Originally designed at the Cloud Computing and Distributed Systems (CLOUDS) Laboratory, Australia, CloudSim has become one among the foremost widespread open supply cloud simulators within the analysis and world. CloudSim is totally written in Java. during this attempt we have a tendency to aim to check a number of such algorithmic programs and see that algorithm are able to do the simplest energy conservation in any given cloud network, whereas simulating the results in CloudSim.

II. Literature survey

S. No.	Title	Author	Year	Proposed methodology, tools and results
1.	Energy-Efficient Management of Data Centre Resources for Cloud Computing: A Vision	Rajkumar Buyya, Anton Beloglazov, Jemal Abawajy	2010	They planned an engineering system and standards for vitality effective Cloud computing. They present our vision, open analysis difficulties, and plus provisioning and designation calculations for energy-efficient management of Cloud computing environments. The planned energy-efficient designation heuristics arrangement server farm assets to client applications in an approach that enhances vitality proficiency of the server farm, whereas conveying the organized Quality of Service (QoS). Specifically, during this paper they direct an outline of analysis in energy-efficient computing and propose: (a) style standards; (b)energy-efficient resource allocation policies (c) numerous open analysis difficulties. They have approved our methodology by directional an execution assessment examines utilizing the CloudSim tool chest.
2.	A Taxonomy and Survey of Energy-Efficient Data Centers and Cloud Computing Systems	Anton Beloglazov, Rajkumar Buyya, Young Choon Lee, Albert Zomaya	2011	They projected performance upgrades driven by the interest of uses from purchaser, logical, and business areas. However, the frequently increasing energy consumption of process frameworks has begun to restrain more execution development owing to irresistible power bills and greenhouse emission impressions. afterward, the target of the computer framework configuration has been captive to power and energy potency. to acknowledge open difficulties within the region and encourage future progressions, it's elementary to integrate and cluster the examination on power-and energy effective set up directed so far. They review completely different key works within the space and guide them onto our scientific categorization to manage future structure and advancement endeavours.

3.	Energy-aware cost prediction and pricing of virtual machines in cloud computing environments	Mohammad Aldossary, Karim Djemame, Ibrahim Alzamil	2018	They planned a unique Cloud framework style that encourages energy economical and skilful cloud operation approach and exhibits a value expectation structure to measure the full-scale expense of VMs counting on their quality use and power utilization. The assessment on a Cloud testbed demonstrates that the planned energy-efficient value prediction system is appropriate anticipating the remaining task at hand, power utilization and evaluating absolute expense of the VMs with great accuracy for various Cloud application work pattern. Additional assessment results demonstrate that the adoption of energy- based valuation by cloud and application suppliers makes a further monetary incentive to each underneath varied economic things.
4.	VMSAGE: A virtual machine scheduling algorithm based on the gravitational effect for green Cloud computing	Xiaolong Xu,Qitong Zhang,Stathis Maneas,Stelios Sotiriadis,Collette Gavan,NikBessis	2018	They advised that a VM programming algorithmic program supported the gravitative impact, referred to as VMSAGE, to reinforce the energy potency of Cloud computing systems. Enlivened by the physical gravitation model, they characterize the thermal repulsion and attraction factors between physical hubs and VMs. To accomplish optimized VM programming, they propose a gravitation function that alludes to the computation of the quality of every VM, host and rack through the calculation, so as to draw the attraction between them and to diminish the machine expense. The experimental results highlight their contribution, in wherever VMSAGE will considerably cut back energy consumption rates and VM migration times.
5.	Virtual Machine Monitoring in Cloud Computing	Nikhil Saswade,Vinayak Bharadi ,Dr.Yogesh Zanzane	2016	They planned a cloud computing facility that serves European shoppers amid European business hours with a precise application (e.g., email) might allocate similar assets to serve North American shoppers amid North America's business hours with an alternate application (e.g., an internet server). This system needs to boost the employment of process power therefore reducing ecological damage additionally since less power, cooling, rack space, so on are needed for a range of functions. Advocates likewise guarantee that cloud computing permits endeavours to induce their applications prepared for action faster, with increased sensibility and fewer support and empowers IT to any or all the more quickly modify assets to satisfy unsteady and erratic business request.
6.	Energy-aware virtual machine allocation for cloud with resource reservation	Xinqian Zhang, Wei, Junlong Zhou,Shiyan Hu,Rajkumar Buyyad	2018	They proposed an improved recreation motor for CloudSim that can quicken the strategy of our formative procedure. Complete test outcomes got from both recreation on CloudSim and genuine cloud conditions exhibit that our approach not solely can quickly achieve a streamlined allotment answer for a cluster of held VMs, yet furthermore can consolidate more VMs with less physical machines to achieve best vitality effectiveness over existing strategies. The general advantage improvement and vitality investment funds achieved by our philosophy can be up to 24% and 41% when appeared differently in relation to stand out strategies, separately.
7.	Optimistic virtual machine placement in cloud data centers using queuing approach	Anitha Ponraj	2015	This paper makes reference to how cloud gives numerous useful administrations to share extensive size of data, stockpiling assets, figuring assets, and give learning to examine. Virtual machines (VMs) for the most part have these information escalated applications. The execution of these applications, I/O information, hand volume, CPU qualities, Virtual machines and the system. In this way, the application employments in the outstanding task at hand have distinctive fruition times dependent on the VM situation choice and substantial information recovery.
8.	Energy-aware virtual machine allocation for cloud with	Xinqian Zhang, Tingming Wu, Mingsong	2016	The creators examine how to lessen the cost of pay-as-you-go style cloud applications, an expanding number of cloud specialist organizations offer asset reservation-based administrations that enable inhabitants to redo their virtual machines (VMs) with explicit time windows and physical assets. In the present exceptionally aggressive distributed computing

	resource reservation	Chen, Tongquan Wei		market, such low vitality effectiveness will altogether diminish the net revenue of cloud specialist co-ops. Along these lines, how to investigate vitality proficient To address this issue, this paper proposes a novel and compelling transformative methodology for VM assignment that can augment the vitality proficiency of a cloud server farm while consolidating progressively held VMs.
9.	ERECT: Energy-efficient reactive scheduling for real-time tasks in heterogeneous virtualized clouds	Huangke Chen, Guipeng Liu, Shu Yin, Xiaocheng Liu, Dishan Qiu	2016	They trusted that high vitality utilization in huge scale cloud server farms has turned into a consuming issue, and productive assignment and asset booking is an alluring method to chop down their vitality utilization while giving palatable administrations to the clients. To take care of the above issue, in this paper, they right off the bat build up a novel booking design that changes the dynamic planning issue into different static timetables. At that point, proposed a vitality effective receptive booking calculation, to be specific ERECT, to plan the continuous undertakings and processing assets in virtualized mists.
10.	Type-aware virtual machine management for energy efficient cloud data centers	Auday Al Dulaimy, Wassim Itani, Rached Zantout, Ahmed Zekri	2014	This paper proposes that to fulfil the developing needs on cloud administrations and applications, a sizeable number of substantial scale cloud server farms, facilitating a large number of heterogeneous servers, is set up by cloud specialist organizations. By and large, the fundamental wellspring of vitality overconsumption in the present server farms is because of the wasteful utilization of the physical servers' assets, which results in poor server use designs. In this way, the key angle is to use the physical assets ideally while serving the cloud client requests. This paper explores the plan and usage of virtual machine the board procedures for vitality proficient cloud server farms.
11.	Energy-aware cost prediction and pricing of virtual machines in cloud computing environments	Alexandros Kostopoulos , Antonis Dimakis, Eleni Agiatzidou	2018	They presumed that with the expanding cost of power, Cloud suppliers consider vitality utilization as one of the significant cost components to be kept up inside their framework. Therefore, different proactive and receptive administration instruments are utilized to productively deal with the cloud assets and lessen the vitality utilization and cost. This paper presents a novel Cloud framework design that encourages a vitality mindful and proficient cloud activity technique and presents a cost forecast system to gauge the complete expense of VMs dependent on their asset use and power utilization.
12.	EATSVM: Energy-Aware Task Scheduling on Cloud Virtual Machines	Leila Ismail, Huned Materwala	2018	They recommended an inescapable selection of distributed computing administrations and applications at a fast rate makes the hidden server farms fuel the issues like carbon impression and the operational expense, brought about by the vitality utilization. Different equipment driven and programming driven methodologies are proposed in the writing to diminish the vitality utilization of the cloud server farms. In this paper, they propose an Energy-Aware Task Scheduling calculation on cloud Virtual Machines (EATSVM) that doles out an errand to the VM where the expansion in vitality utilization is the least, considering both dynamic and inert VMs.
13.	Power and resource-aware virtual machine placement for IaaS cloud	Madnesh K.Gupta, Ankit Jain, Tarachand Amgoth	2018	In the virtualization innovation, they trust that distributed computing is a pool of plenteous registering assets and conveys on-request Internet-based processing administrations. One of the testing issues in the virtualization is the position of virtual machines (VMs) on the physical machines (PMs) with the end goal that the registering assets can be used productively. Besides, imbalanced use of multi-dimensional assets may prompt by and large asset wastage and SLA infringement of a cloud server farm. In this paper, they propose another VM arrangement calculation called multi-objective virtual machine situation (MOVMP) for IaaS cloud.

14.	An efficient IoT cloud energy consumption based on genetic algorithm	Farnoosh Farhadian, Mohammad Mansour	2017	In the paper they exhibited that in a substantial scale IoT framework, ideal allotment of virtual machines to the physical hosts prompts diminish vitality utilization of server farms. Also, it might anticipate contamination of nature and improve the proficiency. The extensive investigation of this examination demonstrates that utilizing the different techniques for virtualization, appropriate mix of these techniques and applying developmental methodologies is promising to grow new calculations. They created novel calculations could improve the vitality proficiency of distributed computing. CloudSim programming is utilized for recreation and NetBeans programming for usage. Significant enhancement for vitality utilization is accomplished through the proposed strategy.
15.	An evergreen cloud: Optimizing energy efficiency in heterogeneous cloud computing architectures	MohamedAbu, SharkhAbdallahShami	2017	In the paper they exhibited that Cloud suppliers are required to execute progressively creative and powerful answers for a rundown of long standing difficulties. Vitality effectiveness in the Cloud server farm is one of the all the more problems that need to be addressed close to the highest priority on that rundown. In this work, they present a novel scientific streamlining model to take care of the issue of vitality productivity in a cloud server farm and an answer dependent on VM relocation that handles this issue and limits vitality effectiveness in comparison to other regular arrangements. This method, named Smart VM Over Provision (SVOP), offers a noteworthy favourable position to cloud suppliers in the situations when live movement of VMs isn't favoured because of its impacts on execution. They assess the previously mentioned arrangements on vitality utilized per server, vitality utilized per served demand, acknowledgment rate, and the quantity of movements performed.
16.	Energy-aware cloud computing	AliVafamehr Mohammad E.Khodayar.	2018	In the paper, they exhibited that Cloud processing, as a drifting model for the data innovation, gives special highlights and openings including adaptability, wide openness and dynamic arrangement of figuring assets with restricted capital speculations. This paper exhibits the criteria, resources, and models for vitality mindful distributed computing practices and imagines a market structure that tends to the effect of the quality and cost of vitality supply on the quality and cost of distributed computing administrations. Vitality the executives rehearses for cloud suppliers at the full scale and miniaturized scale levels to improve the expense and unwavering quality of cloud administrations are exhibited.
17.	Reliability and energy efficiency in cloud computing systems: Survey and taxonomy	YogeshSharma, BahmanJavadi, WeishengSi, DanielSun	2016	In the paper they exhibited that it has turned out to be critical to give on-request benefits powerfully as indicated by the client's necessities. Unwavering quality and vitality effectiveness are two key difficulties in distributed computing frameworks (CCS) that need watchful consideration and examination. This paper exhibits an exhaustive audit of existing procedures for unwavering quality and vitality effectiveness and their exchange off in distributed computing. They additionally talk about the orders on asset disappointments, adaptation to internal failure components and vitality the board instruments in cloud frameworks.
18.	Self-adaptive resource allocation for energy-aware VM placement in dynamic clouds	Han-PengJiang, Wei-MeiChen	2016	In the paper, they displayed that to help the huge cloud benefits, a server farm is worked with a huge number of servers called a server farm arrange (DCN). Alongside the advancement of virtualization, the server farm director conducts virtual machine (VM) resizing and live movements to alter the assignment of VMs and improve the server usage. In this paper, they propose an online asset allotment calculation utilizing VM combination to accomplish vitality proficiency and lessen administration level understanding (SLA) infringement of server farms while considering the power utilization of servers, the quantity of relocations, and the way length of movements in DCNs.

19.	Energy efficiency for cloud computing system based on predictive optimization	Dinh-MaoBui, YongIkYoon, Eui-NamHuh, SungIkJun, SungyoungLee	2018	In this paper, they presented that the majority of the explanations are associated to the operational budget and also the environmental problems. In the paper, they suggested an energy-efficient answer for orchestrating the resource in cloud computing. In nature, the planned approach initially predicts the resource utilization of the approaching period on the basis of the Gaussian process regression method. Finally, a corresponding migrating instruction is issued to stack the virtual machines and switch off the idle physical servers to accomplish the target of energy savings. Through the analysis, they show that the suggested approach is able to accomplish a valuable output in minimising the energy consumption further preserving the system performance.
20.	A three-dimensional virtual resource scheduling method for energy saving in cloud computing	WeiZhu, YiZhuang, LongZhang	2014	The authors suggested a three-dimensional virtual resource scheduling technique for energy saving in cloud computing (TVRSM). In TVRSM, the process of virtual resource scheduling is categorised into three stages: virtual resource allocation, virtual resource scheduling and virtual resource optimization. Due to each stage possessing different objective, they designed three algorithms. The simulation results testify that the TVRSM is able to effectively allocate and manage the virtual resources in the cloud data centre. TVRSM would be able to considerably scale back the energy consumption of the cloud data centre and significantly minimize the quantity of violations of Service Level Agreement (SLA).

III. Methodology

i. Tools employed:

The project was developed in Java using Eclipse and CloudSim. The inbuilt java files provide the start of the implementation in CloudSim which includes files like workload, timeshared, space-shared etc.

ii. Concept of scheduling:

As we run the CloudSim tool, an entity named as 'Cloud Information Service' is created. It is a registry that contains the info of the resources. A datacentre is registered to the CIS. The datacentre contains the host that has the hardware specifications like RAM and processing elements which can vary from host to host and also bandwidth. The host works in a virtual environment and the host is divided into virtual machines. A datacentre contains a host and a host contains a number of virtual machines.

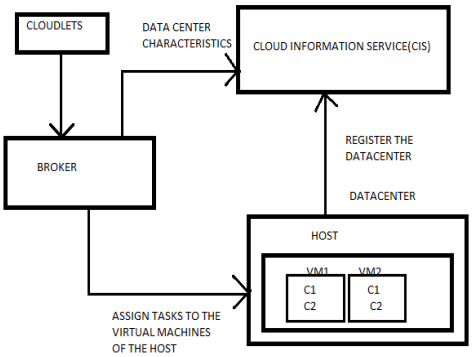

Fig 1. Flowchart visualization of the cloud infrastructure

The Broker is an entity present in the virtual cloud environment which will submit tasks to the datacentre. Broker is a datacentre broker class. At the initial stage, it gains the information of the

resources that are registered with the Cloud Information Service. It means it now gains access to the datacentre characteristics that are present in the CIS. The tasks present in the cloud environment are called Cloudlets and these are submitted to the broker. Once the broker has both the tasks and the data centre information, it assigns these cloudlets to the virtual machines present in the host of the datacentre.

This particular model works on various kinds of policies: VM Allocation policy which is used by the datacentre, VM Scheduler Policy used by the Host and the Cloudlet Scheduler Policy that is used by the virtual machine. All these policies are either time shared or space shared. In timeshared, each virtual machine has been provided equal amount of time and each space shared, all the VMs in the host of the datacentre gets access to equal resources

iii. Algorithms employed:

a. FCFS: First Come First Serve algorithm schedules the processes in the same order that they arrived or, in other words, requested the CPU.
b. SJF: The Longest Job First algorithm priorities the processes in the descending order of their burst time. In case, more than one processes have the same burst time, the algorithm relies on FCFS to break the tie. It is of two types: pre-emptive and non-preemptive. In Pre-emptive mode, the descending order is of the remaining burst time and not the total burst time.
c. LJF: Shortest Job First algorithm orders the processes on the basis of their burst time, with the process with the least burst time scheduled first.

iv. Functional Description:

There is one critical section of the scheduling where the different algorithms are implemented, which is the submitcloudlets() function. Here the scheduling is carried on, the pseudo-code for which is listed below:

Phase 1:
i. Initialize vmIndex to zero
ii. Create an ArrrayList of Cloudlets called sortList.
iii. Create an ArrayList of Cloudlets called tempList.

Phase 2 for SJF:

1. Add all the cloudlets to the tempList.
2. Assign the value of number of total cloudlets to totalCloudlets.
3. Sort in ascending order of length for SJF
   A. From the 0 to the totalCloudlets
      1. Assign the first cloudlet to smallestCloudlet
      2. Traverse through the tempList and check if each of the other cloudlets have an execution time shorter than smallestCloudlet.
      3. If yes, then that cloudlet is assigned as the smallestCloudlet.
      4. Add smallestCloudlet to the sortList.
      5. Remove smallestCloudlet from the tempList.

Phase 2 for FCFS:

1. Add all the cloudlets to the sortList.

Phase 2 for LJF:

1. Add all the cloudlets to the tempList.
2. Assign the value of number of total cloudlets to totalCloudlets.
3. Sort in descending order of length for SJF
   A. From the 0 to the totalCloudlets

1. Assign the first cloudlet to largestCloudlet.
2. Traverse through the tempList and check if each of the other cloudlets have an execution time longer than largestCloudlet.
3. If yes, then that cloudlet is assigned as the largestCloudlet.
4. Add largestCloudlet to the sortList.
5. Remove largestCloudlet from the tempList.

Once the sortList is created, it is list of cloudlets that is dealt by the VM in a procedural manner and assigned, worked on and finally decommissioned.

IV. Results

As mentioned above, we are implementing three basic resource allocation algorithms, commonly used to deploy tasks for various VMs in a cluster network. The first algorithm is the FCFS algorithm that treats the cloudlets in a serial manner in the order of their arrival. The next algorithm is the LJF algorithm that takes the size of the cloudlets formed and entertains the one with the longest length first. The SJF algorithm does the exact opposite of that when it deploys the cloudlet with the smallest workload first. The length of the cloudlets are randomized and the data centre deals with the algorithms to be implemented and employs the above algorithms based on the order of assignment in the submitcloudlets() function.

The following testing has been done on a set of 10 virtual machines that have to deal with the workload of 40 cloudlets. The following patterns were found during testing of the total amount of time taken by each algorithm in creation, allocation, relocation and destruction of events.

FCFS Scheduling Algorithm		
Number of VM	Test Number	Time taken (in seconds)
10	1	9.71
Number of Cloudlets	2	9.21
40	3	9.45
	4	9.8
	5	9.47
	6	9.73
	7	9.62
	8	9.35
	9	9.55
	10	9.68

Table 1. Time taken for FCFS algorithm

LJF Scheduling Algorithm		
Number of VM	Test Number	Time taken (in seconds)
10	1	9.48
Number of Cloudlets	2	10.21
40	3	9.67
	4	9.91
	5	10.03
	6	9.56
	7	9.52
	8	9.84
	9	10.12
	10	9.79

Table 2. Time taken for LJF algorithm

SJF Scheduling Algorithm		
Number of VM	Test Number	Time taken (in seconds)
10	1	8.99
Number of Cloudlets	2	9.27
40	3	9.12
	4	9.23
	5	9.18
	6	9.03
	7	9.17
	8	9.17
	9	9.24
	10	8.83

Table 3. Time taken for SJF algorithm

We can observe from the above tables that the algorithm longest job first took the most time to complete the job for all test cases. This is because the longer task that occur in the beginning become the bottlenecks for the assignment of the other cloudlets that are waiting in the queue. The next most efficient algorithm is the first

come first serve algorithm that has lesser bottlenecks as the heavy tasks are distributed randomly in the queue and hence do not always obstruct all the other waiting cloudlets. The best algorithm among these three turns out to be the shortest job first algorithm as here the execution time as well as the waiting time is minimum as the workload cloudlets are arranged in the ascending order of size, hence no cloud becomes obstructive for the next light-weight cloudlet. Therefore, the starvation is rarely seen in this algorithm scheduling. Given below is the comparative charts of the average cloudlet scheduling time for each algorithm and we can easily visualize which algorithm is the most optimum to be used in a real cloudlet cluster network.

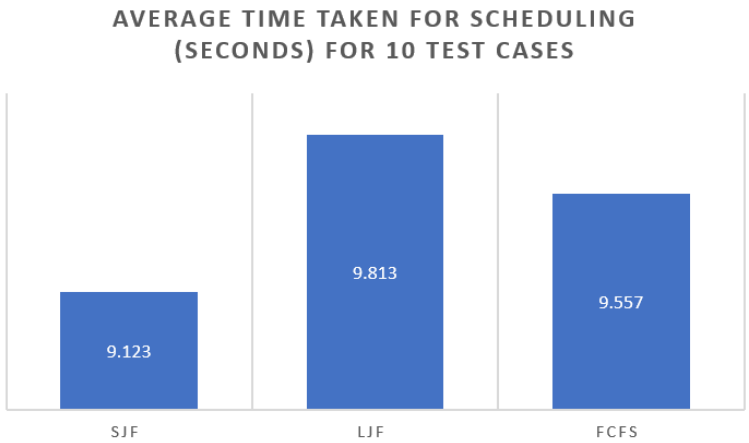

Fig 2. Comparing the average time for each algorithm for 10 test cases

It is widely known in today's world that time equals money, and in the case of virtualized clouds, the lesser the amount of time taken in commissioning the VMs in a cluster, the lesser amount of energy is consumed. This way the setting up and allocation of VMs in a cluster is not only pocket friendly but also environment friendly. In todays world, where 3% of the total electrical energy is consumed by cloud computing, any efforts to reduce this number are needed. By reducing the time needed for the commissioning of the virtual machines, we have been successful in achieving just that.

V. Future Work

The platform in which these energy efficiency scheduling algorithms are constructed can be made more interactive in the sense that new tasks (in cloud computing environments as cloudlets) can be added on the go and the dynamic scheduling of those jobs are done based on the algorithm that we are currently executing. Many new scheduling algorithms have come up that might prove to be more efficient that the ones that are currently being executed, such as Round Robin, Priority queue, Min-Max, Multiple Level queue scheduling algorithm. The dynamic scheduling also finds a scope in this virtualized cloud environment. Automatic scheduling of the tasks (or cloudlets) in case of a failure of a virtual machine can also be incorporated in this environment in future.

VI. Conclusion

The comparison of the three algorithms showed us that the LJG took the longest time to complete while the most efficient algorithm was SJF. When contrasted with LJF and SJF, FCFS took medium amount of execution time. Starvation was seen the least in SJF. Energy efficiency is important for better system performance. By understanding the effectiveness of different algorithms separately and when against each other, we can provide a more proficient way of execution of processes in lesser total time and total waiting time. This in turn automatically translates to having better energy efficiency in a cluster cloud due to decreased migration time and better inter-module communication.

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