World Wide Journal of Multidisciplinary Research and Development

WWJMRD 2017; 3(12): 491-497
www.wwjmrd.com
International Journal
Peer Reviewed Journal
Refereed Journal
Indexed Journal
UGC Approved Journal
Impact Factor MJIF: 4.25
E-ISSN: 2454-6615

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A Review on Energy Efficient Resource Allocation in Cloud Computing Environments

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Abstract
Cloud computing has rapidly emerged as a successful paradigm for providing IT infrastructure, resources and services on a pay-per-use basis over the past few years. As, the wider adoption of Cloud and virtualization technologies has led to the establishment of large scale data centers that consume excessive energy and have significant carbon footprints, energy efficiency is becoming increasingly important for data centers and Cloud. Today data centers energy consumption represents 3 percent of all global electricity production and is estimated to further rise in the future. Cloud led to the establishment of large data centers that contribute in the energy consumed worldwide and consequently the carbon emission and environmental drawbacks. Green Cloud computing evolves around the development of algorithms that decreases the energy consumption and became an active research area. Green cloud strategies are proposed and tested via a broad range of assumptions. Surveying these strategies can identify the fitness of them in achieving the common objectives along with the energy consumption. We identified the way energy consumption is observed and what energy saving methods are applied. Based on that we present a taxonomy and analysis of their strength and weakness of the existing methods. Ultimately, regarding the result of the analysis and trends for future research in green Cloud computing is identified.

Keywords: energy consumption, energy measurement, Green cloud, Energy-aware cloud, ENERGY-AWARE provisioning.

Introduction
The development in computer and communication technologies has led to a new computing paradigm called Cloud computing, which delivers computing services to users as utilities in a pay-as-you-go manner [1]. Cloud providers offer various types of services, such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). Service providers make use of IaaS and PaaS to deploy their services without concerns about managing physical resources. Under the Cloud computing model, users can access on-demand and pay-per-use services anywhere in the world.

Cloud computing is evolved from grid computing in recent years due to increased utilization of virtualization at datacenter. It provides updated services and online resources required for the clients without changing their existing infrastructure. Due to the increasing demand of cloud services, size of the data center is exponentially increasing and more servers are needed to full-fill this demand. Hence, the data center generates more heat, and therefore more cooling devices are required to keep the data center at a specified temperature resulting in more energy consumption and CO2 emission. Therefore, this is an important research area of Green Cloud Computing and hence there is a need of energy efficient resources allocation at the data center in order to reduce the total energy cost. Major cloud service providers like Amazon, Facebook, Google etc., and keep data centers in cold places and thus reduces the energy cost. A recent study shows that these data centers will consume 2% of the total worldwide energy consumption by 2020 [2]. The demand for overall energy requirement at data center is rapidly increasing at the rate of 18% every year. Energy efficiency is becoming increasingly important for Cloud data centers. Their growing scale and their wide use have made a great issue of power consumption. Before beginning to solve the problem, it important to study it in depth and to identify the reasons behind it. The main objective of this work is to present our vision, discuss challenges in energy-aware resource management, and develop efficient policies and algorithms for virtualized data centers so that Cloud computing can be a more sustainable and eco-friendly mainstream technology to drive commercial, scientific, and technological advancements for future generations.

Literature Review

Neeraj Kumar Sharma and G. Ram Mohana Reddy et al. [2] proposed genetic algorithm for energy efficient virtual machine allocation at data center. Genetic algorithm (GA) capable of saving energy of data center and also its helps to avoiding the service level agreement violation. This paper deals with the design of an energy efficient algorithm for optimized resources allocation at data center using combined approach of Dynamic Voltage Frequency Scaling (DVFS) and Genetic algorithm (GA).

Anton Beloglazov, Rajkumar Buyya et al.[3] presented an energy efficient resource manage ment in virtualized cloud data centers... this proposed approach helps to minimize the cost and gives essential quality of services. virtual network topologies established between VMs and thermal state of computing nodes. The results show that the proposed technique brings substantial energy savings, while ensuring reliable QoS.

A.Paulin Florence et al. [4] proposed energy aware cloud computional cloud. In this paper, a new energy aware load balancer is proposed and then implemented in cloud simulator. Proposed approach is implemented by java language. It minimize energy consumption and allocates the job dynamically to a particular VM selected based on best fit strategy and adjust the frequency of the VM depending upon whether job is CPU bound or I/O bound. The VM frequency is adjusted to the maximum if the job is CPU bound or otherwise it is kept to a minimum. Thus proves to be more efficient in terms of energy consumption.

Santanu Dam, Gopa Mandal et al. [5] in this paper load balancing strategy has been presented. This paper proposes a novel ant colony based algorithm to balance the load by searching under loaded node. Proposed load balancing strategy has been simulated using the.Cloud Analyst is used to simulate the load balancing strategy.

Deepak puthal, sambit mishra et al.[6] This paper discussed the emerging research issues that pursued the advance scientific features of cloud computing with layer wise classification of the cloud services, and highlighted the subsequent guidelines of research facing the both industry and academic community. In this study cloud computing architecture and security problem in cloud computing based on its service layer has been discussed.

Potential power consuming units in cloud datacenters

To improve energy effiiency in the Cloud, it is important to study the power in typical data centers and to understand how power is distributed. In fact, more than half of the electrical power is feeding the IT loads. According to the EPA's Report to Congress on Server and Data Center Energy [7], servers consume 80% of the total IT load and 40% of total data center power consumption. The rest ofpower is consumed by other devices like transformers, distribution wiring, air conditioners, pumps, and lighting. The power consumption of cooling equipments is important but it is proportional to the IT power consumption. Technologies like free cooling that are used by big companies (e.g. Google, Facebook, ebay...), are interesting for reducing the power consumption of cooling. These approaches lower the air temperature in data centers by using naturally cool air or water instead of mechanical refrigeration. As a result, the electrical power needed for cooling has enormously decreased. Savings can even reach 100% in case of zero refrigeration which is possible in many climates.

Major causes of energy waste

As explained in the last section, servers are the main power consumers in Cloud data centers. The key reasons for this huge consumption are the following:

Low server utilization:

As data centers are growing in size, the number of servers is continuously increasing. Most data center servers are underused. According to the Natural Resources Defense Council (NRDC) report [8][9], average server utilization remained static between 12% and 18% from 2006 and 2012, while servers draw between 60% and 90% of peak power. Consolidating virtual servers on a smaller number of hosts allows running the same applications with much lower power consumption. By increasing server utilization, the number of required servers and overall energy use will be greatly reduced.

Idle power waste

Data center servers sit idly and are not processing useful work about 85-95% of the time[9]. An idle server consumes about 70% of its peak power even if it is not used [10]. This waste of idle power is considered as a major cause of energy inefficiency. Hence, idle servers in data centers could be turned on_ to reduce energy consumption.

Lack of a standardized metric of server energy efficiency

To insure energy efficiency optimizations, it is important to use energy efficiency metric for servers to sort them according to their energy efficiency and to enable scheduling algorithms to make decisions and to select the best resources to maximize energy efficiency. Even though some metrics focusing on IT efficiency have appeared in recent years [11], they do not provide a simple benchmark that can drive the optimization of energy efficiency [9].

Energy efficient solutions are still not widely adopted

As stated in the NRDC report [9], many big Cloud farms do a great job on energy efficiency, but represent less than 5% of the global data centers' energy use. The other 95% small, medium, corporate and multi-tenant operations are much less efficient on average. Hence, energy efficiency best practices should be more adopted and used especially for small and medium sized data centers that are typically very inefficient and consume about half of the amount of power consumed by all the data centers.

Energy Consumption
Energy consumption has been an important consideration in the IT industry for some time. It has been investigated in the context of Grid [12-13], Clusters [14-16], High Performance Computing (HPC) [17-18] or simple computer systems [19]. More recently, Cloud computing has led to the emergence of large data centres. Energy consumption contributes to 50% of the operating cost in data centres [20]. Consequently, existing research has been applied to the Cloud and new specialised approaches have been developed. Saving energy in large-scale data centres requires hardware and software optimisation. Hardware improvement is an active area of research. For instance, the peak energy consumption of servers is optimised by modifications of the hardware such as the introduction of a power controller proposed by Lefurgy et al [21]. However, the optimal use of the available hardware depends on the effectiveness of the algorithms that control it. To make data centres more energy-efficient there is a need for developing energy-efficient provisioning algorithms. Newly devised energy-efficient provisioning algorithms are tested either on a data centre or using simulation software. In the case of experiments on a data centre, the energy/power data is collected from the specific hardware. A simulation package applies a mathematical formula to approximate the energy/power consumption.

Energy Measurement
One of the factors in energy related studies is the way the energy/power is measured or calculated. Energy refers to the total flow of current in a period of time and is measured in Watts (W), whereas power refers to the flow of current in a unit of time and is measured in Watts per hour/second. Whether the explicit objective is energy orpower, the goal of many studies is to minimise the cost of electricity necessary to execute tasks in the Cloud. In some studies, the actual consumption is measured by connecting a meter to the servers, in others a formula or a set of rules are developed to approximate the consumption. Power meters that are connected to motherboards also consume energy that is included in the measurements, but this consumption is generally regarded as negligible.
Real hardware for experimental evaluation is not always available to researchers, who find it easier to use simulation packages instead. Some energy-aware simulation packages are GreenCloud [22-23], MDCSim [24], CloudSim [25-26] and GSSIM [27-28]. A 2013 study by Kaur compares the characteristics of MDCSim, CloudSim and GreenCloud [29]. Among the available packages, CloudSim has been the most widely used by scholars. The reason can lie in the fact that the CloudSim package is constantly being updated by Cloud Laboratory in University of Melbourne. New trends in research are being implemented /tested and different workload from physical hardware is included. A review of CloudSim and its various versions can be found in research by Goyal et al [30]. An energy-aware simulation package has to include formulae for calculating the energy consumption associated with a specific resource utilisation.CPU utilisation is commonly assumed to be the main contributor to energy consumption, an assumption that has been fortified by experiments in the Green Computing Lab at Swinburne University of Technology, Melbourne, Australia [31]. CPU Energy/power consumption can be divided into constant and dynamic consumption. Constant consumption is hardware-dependent and measured when the system is idle. Dynamic energy/power consumption depends on the frequency of the processor while executing the workload. Dynamic power was defined as P = C.f3 by Kim et al [32], where P is the power consumption, C is a coefficient and f is the frequency of the processor. To obtain total energy consumption, this value should be added to the constant power consumption. The experiments by Lien et al shaped a set of rules that were used [34] and modified [35] by Hsu et al. Eq.1 [33] provides a set of rules that determines the energy consumption for VM
number i, Vi, at the time t using α, the idle energy consumption and β =α.E_{t} =

$$\begin{Bmatrix} \alpha & idle \\ \beta+\alpha & 0\% < CPU\ Util \ll 50\% \\ 2\beta+\alpha & 50\% < CPU\ Util \ll 70\% \\ 3\beta+\alpha & 70\% < CPU\ Util \ll 80\% \\ 4\beta+\alpha & 80\% < CPU\ Util \ll 90\% \\ 5\beta+\alpha & 90\% < CPU\ Util \ll 100\% \end{Bmatrix}$$

The quantities were adjusted later in Hsu et al [42] as follows:

$$E_{t} = \begin{Bmatrix} \alpha & idle \\ \beta+\alpha & 0\% < CPU\ Util \ll 50\% \\ 2\beta+\alpha & 50\% < CPU\ Util \ll 70\% \\ 3\beta+\alpha & 70\% < CPU\ Util \ll 80\% \\ 4\beta+\alpha & 80\% < CPU\ Util \ll 90\% \\ 5\beta+\alpha & 90\% < CPU\ Util \ll 100\% \end{Bmatrix}$$

According to the above mentioned energy models, a specific frequency in the system is associated with different values in different models. Although, they might behave relatively the same, the differences in details can lead to different results when it comes to comparison.

Other Goals and Objectives
Energy/power savings have been a major consideration in the complex context of the Cloud that affect many aspects of the system. Many studies have investigated the Cloud from the point of view of these aspects which often present themselves as trade-offs between optimisation goals. These aspects include:

Temperature: High energy consumption leads to the production of more heat that again necessitates more cooling devices, which, in turn, add to the energy consumption.

Resource utilization: Resource utilisation, CPU utilisation in particular, is the most significant contributor to the energy consumption of the system. Increasing the utilisation of the available resources helps keep the number of active servers at a minimum, which decreases the energy consumption. Completion or response time: Keeping a minimal number of servers active increases the probability an increase in completion/response time.

SLA/QoS: Compressing the workload on the minimum number of servers can also cause violation of QoS/SLA.

Deadline: Deadlines are an issue in the provisioning problem in real-time systems. Deadline violations can be incurred by strategies used for decreasing the energy consumption.

Performance: The definition of performance varies in the literature. It is sometimes reported as the number of finished tasks or the utilisation of a resource per unit of time.

Cost: Cost is usually discussed as a consequence of either energy consumption or resource utilisation or both.

Figure 1 depicts the relationships between these factors. Energy/power consumption is directly related to resource utilisation, Higher the resource utilisation, larger the power consumption and shorter the completion time. Resource utilisation influences the temperature of the resources and entails cooling systems, which leads to higher costs. While a high resource utilisation ideally indicates a well utilised system with high efficiency, it can increase the chances of hardware failure. Shorter completion times improve performance and can be a crucial factor when dealing with real-time systems and application deadlines. SLA/QoS may define requirements regarding completion time, deadline, performance or cost, or a combination of these.
Some studies attempt to achieve a balance between these factors. Torres et al [36] minimised the number of active nodes to decrease the resource wastage and energy consumption while aiming for minimum performance degradation. Bobroff et al [37] decreased the resource utilisation by dynamically migrating VMs between hosts while satisfying the SLA. Moore et al [38] investigated the trade-off between the resource utilisation and the cost of cooling the system. Several studies investigated the impact of resource provisioning for real-time tasks in an environment sensitive to deadlines [32][39-41].

Green cloud architecture
Clouds aim to drive the design of the next generation data centers by architecting them as networks of virtual services (hardware, database, user-interface, application logic) so that users can access and deploy applications from anywhere in the world on demand at competitive costs depending on their QoS requirements [42]. Fig. 1 shows the high-level architecture for supporting energy-efficient service allocation in a Green Cloud computing infrastructure [6]. There are basically four main entities involved:

1. Consumers/Brokers: Cloud consumers or their brokers submit service requests from anywhere in the world to the Cloud. It is important to notice that there can be a difference between Cloud consumers and users of deployed services. For instance, a consumer can be a company deploying a web-application, which presents varying workload according to the number of ''users'' accessing it.
2. Green Service Allocator: Acts as the interface between the Cloud infrastructure and consumers. It requires the interaction of the following components to support the energy-efficient resource management:

(a) Green Negotiator: Negotiates with the consumers/brokers to finalize the SLAs with specified prices and penalties (for violations of the SLAs) between the Cloud provider and consumer depending on the consumer's QoS requirements and energy saving schemes. In case of web-applications, for instance, a QoS metric can be 95% of requests being served in less than 3 s.

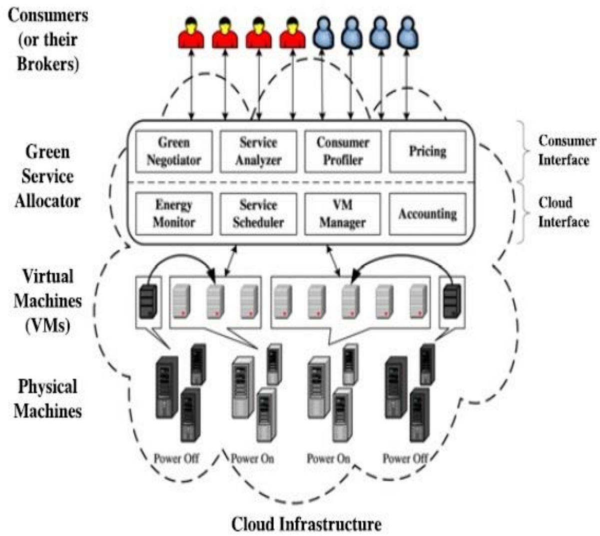

Fig. 2. The high-level system architecture.

(b) Service Analyzer: Interprets and analyzes the service requirements of a submitted request before accepting it. Hence, it needs the latest load and energy information from VM Manager and Energy Monitor respectively.

(c) Consumer Profiler: Gathers specific characteristics of consumers so that important consumers can be granted special privileges and prioritized over other consumers.

(d) Pricing: Decides how service requests are charged to manage the supply and demand of computing resources and facilitate in prioritizing service allocations effectively.

(e) Energy Monitor: Observes energy consumption caused by VMs and physical machines and provides this information to the VM manager to make energy-efficient resource allocation decisions.

(f) Service Scheduler: Assigns requests to VMs and determines resource entitlements for the allocated VMs. If the autoscaling functionality has been requested by a customer, it also decides when VMs are to be added or removed to meet the demand.

(g) VMManager: Keeps track of the availability of VMs and their resource usage. It is in charge of provisioning new VMs as well as reallocating VMs across physical machines to adapt the placement.

(h) Accounting: Monitors the actual usage of resources by VMs and accounts for the resource usage costs. Historical data of the resource usage can be used to improve resource allocation decisions.

3. VMs: Multiple VMs can be dynamically started and stopped on a single physical machine according to incoming requests, hence providing the flexibility of configuring various partitions of resources on the same physical machine to different requirements of service requests. Multiple VMs can concurrently run applications based on different operating system environments on a single physical machine. By dynamically migrating VMs across physical machines, workloads can be consolidated and unused resources can be switched to a low-power mode, turned off or configured to operate at low-performance levels (e.g. using DVFS) in order to save energy.

4. Physical Machines: The underlying physical computing servers provide the hardware infrastructure for creating virtualized resources to meet service demands.

Energy-Aware Provisioning

Energy-aware provisioning requires the deployment of algorithms that lead to lower energy/power consumption. According to the time these strategies come into action it can be categorized as energy-aware scheduling or rescheduling.

Energy Saving Strategies

The two main strategies applied for energy saving in Cloud-related studies are host switching and Dynamic Voltage and Frequency Scaling (DVFS). Switching off idle hosts reduces the energy consumption and the system responds to the requests with the available hosts. The strategy of switching hosts on and off has been studied by Mao et al [43] and extended in Mao and Humphrey[50], where the effect on deadlines and cost were investigated.

The significance of the energy savings achieved by switching off hosts may be due to the fact that an idle host still consumes up to 70% of its peak power [44 - 45]. Switching hosts on again incurs a short interval of peak energy consumption and possible delays to the system. DVFS saves energy by reducing the frequency of hosts while keeping them active. A strict implementation of DVFS decreases the frequency of the processors to a level where the deadlines are barely met, which can lead to deadline violations in a sensitive system. Nonetheless, the server switching and frequency alteration have proven to be effective [46] and are commonly used.

Conclusion

The Cloud resource provisioning is an area yet to be fully investigated. It plays an important role in providing reliable service in a satisfactory level regarding energy consumption. The relation between energy consumption and other sometimes conflicting objectives in the Cloud make the research in this area of high importance and complexity.

In this paper, details of the studies related to energy aware Cloud provisioning are reviewed to provide insights. The aim was to describe multiple aspects and assumption of the studies to identify the differences. Details include the way energy consumption is obtained and the differences it makes, the energy saving strategies and the effect of hypervisor on the reported results. Also, other goals that might be simultaneously considered at the time of experiment and their impact on and from energy consumption are discussed. We noted that there are details in the experiments that can potentially change the results of the algorithms. This includes but is not limited to the way energy consumption is collected. Formulae and rule-based approximations give a rough estimate of the real energy consumption but makes simulation possible. On the other hand power meters attached to the hardware might read different values according to where they are connected and how often the meter is being read. Power meters circuits also add to the energy consumption that is being measured. Therefore, the more often the power is read the more the power meter energy will be added and less reading gives less accuracy to the power reading as there are less reading points.

Sbtrategies applied to formulate the Cloud provisioning problem are mainly defined as a trade-off between minimizing energy consumption and other goals as either a simple trade-off or a multi-objective optimization problem. It might also be described as a bin packing problem where available resources are the bin that accommodates applications/application's VMs. Regarding the problem formulation a solution strategy is developed. Solutions are categorized as deterministic and heuristic. The review and analysis in this paper have provided an overview of available provisioning strategies and their characteristics to support researchers in finding the research gap. It also helps to detect the possible deviations from the reported results. Identified challenges are to suggest new trends and paths that requires further investigation. We consider this review as a reference and a basis for further research work.

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