An Energy Efficient Algorithm for Virtual Machine Allocation in Cloud Datacenters

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Abstract. In cloud datacenters, virtual machine (VM) allocation in a power efficient way remains a critical research problem. There are a number of algorithms for allocating the workload among different machines. However, existing works do not consider more than one energy efficient host, thus they are not efficient for large scale cloud datacenters. In this paper, we propose a VM allocation algorithm to achieve higher energy efficiency in large scale cloud datacenters. Simulation result shows that, compared with BRS, RR and MPD algorithms, our algorithms can achieve 23 %, 23 % and 9 % more power efficiency in large scale cloud environment.

Keywords: Cloud computing · Dynamic Voltage and Frequency Scaling (DVFS) · Data centers · Bin packing

1 Introduction

Cloud computing [1] is a popular computing service model. Users can easily access and manage a pool of computing resources like storage, networks, servers and other client applications in the cloud. This on-demand technology service helps user speedily release with trivial management efforts [2]. Clouds try to decrease the price of software and hardware management.

Managing infrastructures cost-efficiently [3] is one of the important tasks in the cloud. Many famous information technology organizations and companies have installed big scale datacenters with thousands of computing servers to provide cloud computing services, such as Google, IBM, Amazon and Microsoft. The incredible growth in the amount and size of datacenters leads to substantial power consumption. According to the report of Environmental Protection Agency (EPA) in USA, datacenters consume around 61TWH of energy in 2006 i.e. 1.5 % of the entire power usage. The report estimated that the power consumption will double in each five years. Inside datacenters 40 % power is consumed by computing infrastructures, 45 % is consumed for the cooling machines and 15 % is lost in the power generation units. The EPA report shows that 70 % power consumption can be saved by applying state-of-art efficiency methods at the cooling, power units and computing infrastructure. Table 1 compares the

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Table 1. Annual saving in 2011 using state-of-art methods

ICT apparatus	2011 energy usage	Power consumption under state-of-art technique
Infrastructure	42.1	18.1
Network devices	4.1	1.7
Storage	4.1	18
Servers	33.7	14.5
Overall	84.1	36.1

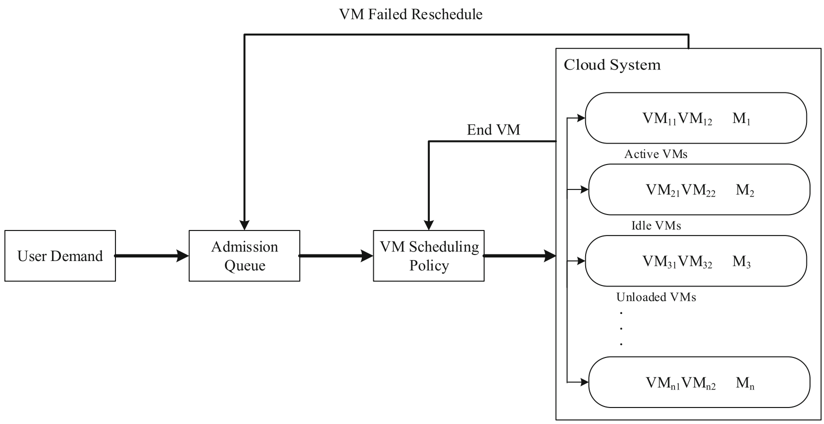


Fig. 1. VM allocation in cloud computing

power consumption of datacenters in 2011 with that under applying the state-of-art methods [4].

VM allocation and placement technique is one of the background technology to achieve this efficiency in cloud infrastructure. VM allocation and placement technique is a method of mapping VMs to physical hosts. After users finish selecting VMs, they'll be allocated to different physical hosts for executing user application. Figure 1 shows that the procedure of VM allocations. VM allocations have a direct impact on the energy consumption since it is one of important parts in the Resource Management (RM). The main purpose of the allocation policy is to allocate the available resources efficiently, i.e., the resource utilization is maximized to reduce power consumption. Providers can shutdown physical host as more as possible while ensure their service needs. Thus the power consumption would be minimized.

To ensure quality of service (QoS), only unused hosts can be shutdown. Thus the critical step is to allocate VMs efficiently, i.e., increasing the utilization of hosts. Since the workload is dynamic and future workload is hard to predict, allocating VM to hosts efficiently is difficult to decide.

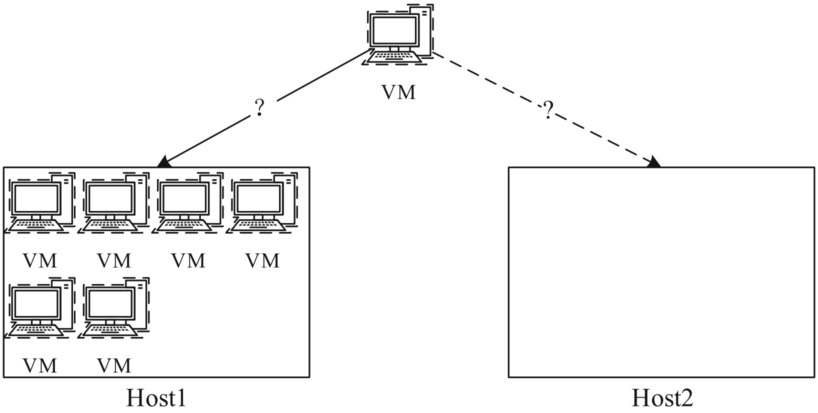


Fig. 2. VM allocation problem as bin packing problem

Efficient VM allocation remains a critical problem. In [5] authors describe VM allocation as a bin packing problem. They propose a best-fit decreasing on VM allocation i.e. power-aware BFD (PABFD). PABFD allocate a VM to a host that will raise least power consumption, it also allocate VMs to a host that has less cores based on CPU utilization. In [6] authors proposed allocation of VMs scheduling algorithm to minimized power consumption during task execution in cloud datacenters environment. In [7] authors proposed VM allocation method. If request does not map to any VM then they focus on near that most suitable VM pattern to the customer to check remain in queue. However, these works do not discuss the condition when more than one energy efficient hosts are available.

In this paper, we concentrate on IaaS clouds, e.g., Amazon EC2. We formulate the problem of VMs allocation as a bin packing problem. The objective is to minimize energy consumption in a datacenters. To overcome the disadvantage of just choosing one host, we proposed Energy Efficient (EE) algorithm by select most energy efficient host first. The proposed algorithm focus on decreasing the power consumption in cloud datacenters. To achieve this goal, we adopt Power Aware (PA), Non-Power Aware (NPA), and Dynamic Voltage Frequency Scheduling (DVFS) techniques to our algorithm. The experiment result shows that our algorithm achieves 23 %, 23 % and 9 % higher power efficiency than BRS, RR and MPD algorithms.

The rest of this paper is organized as follows: we formulate the VM allocation problem as a bin packing problem in Sect. 2. In Sect. 3 we propose a novel VM allocation algorithm to achieve higher energy efficiency. In Sect. 4, we evaluate the proposed technique, and compare the performance with traditional heuristics in an event driven simulator. Sects. 5 and 6 show some related works and conclusion respectively.

2 Problem Fomulation

In this section, we'll formulate the VM allocation problem as a bin packing problem.

VM allocation problem can be seen as a bin packing problem. Figure 2 shows the VM allocation problem. VMs are regarded as items and host physical machines are treated as bins. Each host has fixed volumes of CPUs, which is the size of each bin.

The computational resources consumed by VMs is regarded as the size of each item. VMs also consume electricity power when they are running on the hosts. These powers are seen as the value of each item. Different from typical bin packing problem, the objective of VM allocation is to minimize the sum power consumed by VMs. To reduce the power consumption, we minimize the number of host that users use. Under the framework of bin packing problem, the sum size of items cannot exceed the capacity of bins, i.e., the sum computational resources consumed by VMs cannot exceed the capacity of hosts. Thus, VM allocation problem is formulated as:

$$min \;\; z = \sum_{j=1}^{n} Y_j \tag{1}$$

$$s.t. \;\; \sum_{i=1}^{n} w_i x_{ij} \leq c_j \tag{2}$$

$$\sum_{j=1}^{n} x_{ij} = 1, \tag{3}$$

where w_i is the computational resources consumed by the ith VM, and c_j denotes the capacity of the jth host. Y_j is a binary variable, meaning whether bin_j is used or not. x_{ij} denotes the decision variable, meaning if $item_i$ is placed in bin_j.

$$Y_j = \begin{cases} 1, & \text{if}\, bin_j \text{ is used} \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

$$x_{ij} = \begin{cases} 1, & \text{if}\, item_i \text{ is placed in}\, bin_j \\ 0, & \text{otherwise.} \end{cases} \tag{5}$$

So far, the VM allocation problem is formulated as a bin packing problem. We treat VMs as items and hosts as bins. The objective of VM allocation is to minimize the power consumption, i.e., minimize the number of used hosts. The constraint is to ensure quality of service.

3 Proposed Algorithm

In this section, we propose the Energy Efficient allocator (EE) algorithm to achieve high energy efficient.

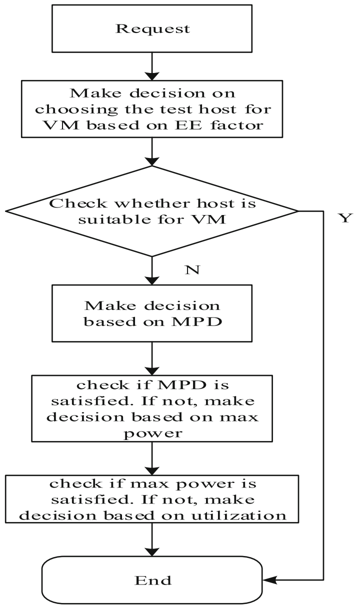


Fig. 3. Flow chart of the EE algorithm

The basic idea of EE algorithm is greedy, i.e., we always select the most energy efficient host to place our VMs. If there are more than one EE hosts, then the allocation is implemented using PABFD. In case PABFD returns more than one energy efficient hosts, then the more utilized host is nominated to reduce the number of migrations. The last step is divided into two different steps. The first one is to select a host that is more utilized to reduce the number of migrations. The second option is to choose a less utilized host to balance the utilization. Figure 3 shows the main procedures of EE algorithm.

To show energy efficiency, we first define a metric to evaluate the energy efficiency. The energy efficiency is the ratio between CPU capacity and energy.

$$H_{EE} = \frac{C_{host}}{P_{max}}, \tag{6}$$

where C_{host} is the entire CPU capacity and P_{max} is the maximum energy consumption of the host.

Algorithm 1 shows details of the Energy Efficient allocator algorithm. First in line 4 we check all hosts whether the VM is suitable or not. If it is suitable, the process will be end. In line 11 we find the most energy efficient host if we have more hosts available. If this condition is not satisfied, we check the most efficient host according to MPD. But this step is very expensive because if we do not have VM but still the author proposed this algorithm and we consider this algorithm and merge with our proposed algorithm to find the best efficient hosts for VM allocation. In line 17, we calculate the minimum power consumption. In line 21, if the power difference and the minimum power consumption are equal, we can find the allocated host and the related host power. In line 27–29, we calculate decision on utilization based on if there is no min power available. When we take decision on utilization, it will increase the utilization of hosts. In line 30, we check the condition for utilization of host. If $Uh > Ua$ is satisfied, we assign host to allocated host. Otherwise, we check for equality of Uh and Ua, and check the total mips of host. Then we allocate the host if line 34 condition is satisfied.

In Algorithm 1, function getpowerafterallocation() returns the total power of host after allocation of VM. Function getutalization() returns CPU current percentage used while gettotalmips() function returns total MIPS that CPU supports. Function getmaxpower() returns host maximum power while getpower function returns host current power usage. Function getMIPS() returns host or VM maximum MIPS utilization.

The time complexity of our algorithm is $O(n)$. Also the space complexity is $O(n)$, and n is related to the number of hosts.

4 Evaluation Results

In this section, we conduct a simulation to evaluate the performance our EE algorithm with BRS, RR and MPD algorithms in CloudSim. We combine these four algorithms with three techniques, i.e., NPA, PA and DVFS to evaluate the performance.

4.1 Simulation Setup

To evaluate our proposed allocation algorithm, we conduct several simulations in an event driven simulation environments, i.e., CloudSim. In CloudSim, the workloads are represented by cloudlets which are submitted to VMs. VMs are placed on the available servers (i.e., hosts) in the datacenter. The processing speed of servers is evaluated by Millions of Instructions Per Second (MIPS) rating.

To analyze the performance of proposed algorithm, we conduct the simulations with small, medium and large size datacenters having heterogeneous machines (Table 2).

- In case of small size datacenters, we choose 10 hosts, 20 VMs and 20 tasks.
- In case of medium size datacenter we have selected 100 hosts, 200 VMs and 200 tasks.
- In case of large size we choose 1000 hosts, 2000 VMs and 2000 tasks.

The detailed configurations for hosts and VMs are as following:

- Hosts: each host has 1 TB of storage, 24 GB RAM, 1 processing entity (PE) and gigabit Ethernet. And hosts adopt Linux and Xen as operating system and virtual machine monitor respectively.
- VMs: each VM requires 1 PE; the processing capacity of each VM are 500, 750, and 1000 MIPS which are create in a round-robin fashion.

Algorithm 1. Allocator EE

```
Input hostlist, VM
Output allocatedhost
Best=0
allocatedhost=host
for each host in list do
  if host is suitable for vm then
    Powerafterallocation= host.getPowerafterallocation()
    if Powerafterallocation is not null then
      MIPS=host.getmips()
      Maxp=host.getmaxpower()
      Powerefficiency=MIPS/MaxPower
      MinPower=max_value
      if Powerefficiency >Best then
        Best=Powerefficiency
        allocatedhost=host
      end if
      if Powerefficiency==Best then
        Powerdiff=Powerallocation-host.getPower ()
        if Powerdiff <MinPower then
          MinPower=Powerdiff
          allocatedhost=host
        end if
        if Powerdiff==MinPower then
          Pa=allocatedhost.getPower()
          Ph=host.getPower()
          if Ph <Pa then
            allocatedhost=host
          end if
          if Ph==Pa then
            Ua=allocatedhost.getutalization()
            Uh=host.getutalization()
            if Uh >Ua then
              allocatedhost=host
            end if
            if Uh==Ua then
              if host.gettotalmips() >allocatedhost.gettotalmips() then
                alloactedhost=host
              end if
            end if
          end if
        end if
      end if
    end if
  end if
end for
return allocatedhost
```

Table 2. Example for heterogeneous datacenter

Hosts	Host1	Host2	Host3	Host4	Host5
MIPS	1000	1500	2000	2500	3000
Power	200	250	300	350	400

– Tasks: every task has 300 bytes of data before and after the processing (Generalized Cloudsim model); every task consists of 10,000, 15,000, 20,000 and 25,000 MIPS which are create in a round-robin fashion.

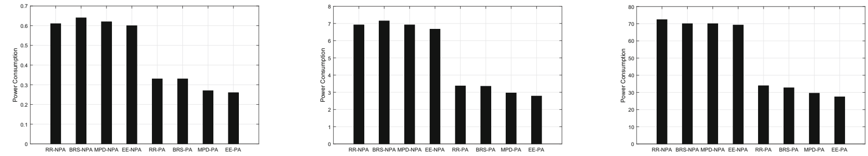
In our simulations, we evaluate the performance of algorithms combined with three datacenter techniques: (1) NPA (which do not support to shutdown unused machines), (2) PA (which support to shut down unused machines) and (3) DVFS idle machine consumes 70 % of its energy and totally used machine consumes 100 % of the energy.

4.2 Simulation Results

To validate our proposed algorithm, the results were compared with two classic scheduling algorithms i.e. Best Resource selection (BRS), Round Robin (RR) and MPD, which is one Cloudsim power management algorithm in terms of cloudlets completion time and power consumption [7]. In the BRS policy the machine with the peak ratio (MIPS in Use/Total no-of-MIPS) is chosen for any VM next in line. This ensure reducing no-of migrations and have affinity to achieve quicker outcomes. In case of RR policy, every VM is allocated to a different machine using circular policy. Machines that can allocate VM are avoided. In case there is no machines talented to accommodate VMs, the allocation is postponed. MPD is used as the vital model of power savings in Cloudsim environment. Each coming VM is allocated to the machine which will consume less power to run the VM.

Figure 4(a), (b) and (c) show the evaluation result under NPA and PA techniques. Figure 4(a) shows the result for small size datacenter. Our proposed algorithm achieves 21 %, 21 % and 3.7 % higher power efficiency than RR, BRS and MPD combined with PA technique. Figure 4(b) shows the result for medium size datacenter. Our proposed algorithm saves 17 %, 16 %, and 6 % more power than RR, BRS and MPD combined with PA technique in this case. Figure 4(c) shows the result for large size datacenter. Our proposed algorithm works 19 %, 16 % and 7.1 % better than RR, BRS and MPD combined with PA technique respectively. Since under NPA technique, all existing algorithms could not make significant progress, we do not show the improving ratio.

Figure 5(a), (b) and (c) show the evaluation result under DVFS technique. Figure 5(a) shows the result for small size datacenter. Our proposed algorithm saves 23 %, 23 % and 9 % more power than RR, BRS and MPD. Figure 5(b) shows the result for medium size datacenter. Our proposed algorithm works 18 %, 13 % better than RR, BRS. But MPD performs the same to our proposed algorithm. Figure 5(c) shows the result for large size datacenter. Our proposed algorithm

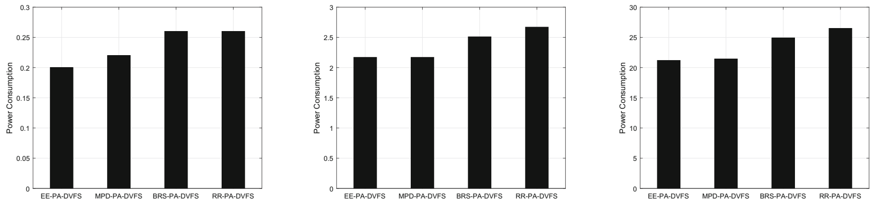


(a) Power consumption evaluations for Small data center

(b) Power consumption evaluations for Medium data center

(c) Power consumption evaluations for Large data center

Fig. 4. Power consumption evaluations among different algorithms for different size data center under NPA and PA techniques



(a) Power consumption evaluations for Small data center

(b) Power consumption evaluations for Medium data center

(c) Power consumption evaluations for Large data center

Fig. 5. Power consumption evaluations of different algorithms for different size data center under DVFS techniques

show better performance than RR, BRS, and MPD at the ratio of 20 %, 14 % and 1.1 % respectively.

To evaluate the performance and stability of our algorithm and other three algorithms, we compare the average power consumption and standard deviation among them. From Table 3 we can see, our proposed algorithm achieves better result in both average power consumption and standard deviation than other three algorithms in case of large size datacenter. Smaller standard deviation shows higher stability of algorithms. Similarly, from Table 4 we can also see that, our proposed algorithm works better than other three existing techniques both in the average and standard deviation.

Table 3. Comparative table for power aware simulation

Experiments	RR		BRS		MPD		EE	
Large size	33.82	0.084	31.77	0.068	29.25	0.036	27.49	0.032
Small size	0.33	0.0074	0.32	0.0088	0.26	0.0057	0.26	0.0057

Table 4. Comparative table for large size DVFS simulation

Experiments	RR		BRS		MPD		EE	
Large size	26.48	0.057	24.97	0.046	21.44	0.038	21.11	0.034

From the above experiments we can see that the proposed method can save 12.8 % power in case of PA and 12.2 % in the case of DVFS enabled techniques. From the analysis, we find that our method saves more power in large scale systems.

5 Related Work

Beloglazov et al. [8] focused on resource management technique that provide quality-of-service constraint and minimizing operating costs. Performing consolidation of VMs according to resource utilization help to save power. Berl et al. [9] used energy efficient mechanism for cloud computing, specifically in the area of networks and hardware framework. It also focuses on decreasing power consumption in software and hardware, improving the load balancing and minimizing communication power consumption. Suri et al. [10] design an allocation algorithm that decrease the load on servers needs to achieve minimum power consumption. In [11], the authors propose a technique that allocates VMs to achieve the goal of decreasing power consumption in virtualized cloud datacenters.

In [5,12–17] power-aware VM allocation techniques for energy efficient RM in cloud datacenters were proposed. In [5] authors proposed allocation of VMs scheduling algorithm to minimized power consumption during task execution in cloud datacenters environment. This paper also concentrate on to shutdown of underutilized hosts and DVFS. In [7] authors proposed VM allocation method. If request does not map to any VM then they focus on near that most suitable VM pattern to the customer to check remain in queue. They also focused on to describe concept of cloud to choose an efficient VM to facilitate customers as well as maintaining QoS and SLA. VM placement are NP-hard problem and still there is no optimal solution. Also, in [18,19] discuss the VM placement and [20,21] discuss affinity aware solution to solve complicated problems. In a datacenters power saving increases by keeping VMs on a physical hosts in an optima way.

In [22] authors formulated score-based scheduling method as hill-climbing algorithm, also focus on principle map searching (host, VM) pairs. Where, the score of each (host, VM) pair is the addition of numerous factors, including resource requirement, power consumption, software and hardware fulfilment. A clouds scheduler can use the metric of performance-per-watt to assign VMs to hosts for energy efficiency. Their proposed approach, i.e. EPOBFs [23] allocates a host that has maximum MIPS/Watts. In [22] authors discussed PA VM allocation heuristics for power-efficient resource management in cloud datacenter. A hybrid VM provisioning method is proposed in [24], which is based on two methods, (i) On Demand (OD) and (ii) Spare Resources (SR). OD policy start the resources when they are wanted. To avoid the requests timeout issue, the authors implemented SR policy to decrease energy consumption on private clouds and avoid SLA violation.

Our proposed solution differs from these existing techniques. We select a more energy efficient host for the VM placement.

6 Conclusion

Cloud computing services enable developers and companies flexibly manage their infrastructure since it provides infinite resources and adopt the pay-as-you-go pricing model. There are certain risks related to cloud computing such as energy cost minimization and carbon dioxide emissions reduction. We formulate the VM allocation problem as a bin packing problem. To achieve power efficiency, we proposed a VM allocation algorithm to place VMs requests on most energy efficient physical hosts. We evaluated the proposed method with three existing algorithms, including BRS, RR and MPD. By using NPA, PA and DVFS enabled techniques in a simulation environment, our algorithms can achieve 23 %, 23 % and 9 % more power efficiency than other algorithms.

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