# Multi-objective Optimization Based Virtual Resource Allocation Strategy for Cloud Computing

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***Abstract*—The increasing requirements on cloud computing entail building up large numbers of large-scale data centers which require a surprising amount of energy. With the gradual depletion and price escalation of traditional energy, operating data center in an energy efficient way is an emerging urgent problem. However, most existing researches of resource allocation in datacenter did not take into full consideration how to decrease energy consumption. In this paper, we formulate the energy efficiency virtual resource allocation for cloud computing as a multi-objective optimization problem, which is then solved by intelligent optimization algorithm. The simulation results reveal that the strategy can successfully generate schedule scheme of different numbers of servers-VMs with diverse characteristics in a reasonable time period and decrease the total operating energy of data center effectively.**

***Keywords- cloud computing; virtual resource allocation; green computing; energy efficiency; multi-objective optimization***

## I. INTRODUCTION

Cloud computing is envisioned as the future IT service paradigm and has attracted tremendous attention from academia and industry. With cloud computing, cloud customers are able to gain virtually infinite capability of computing and storage through simple devices with special software, and pay for the services in pay-as-you-go manner. As a result, customers no longer need to worry about the cost of IT infrastructure. In cloud computing age, capabilities such as computing and storage are organized as public utility just like water and electricity system. All these capabilities are provided by resource pools, i.e., data centers composed of a great quantity of infrastructure including server, switch, etc. These infrastructures are automatically managed, QOS guaranteed, scalable and reliable. One of the typical cloud computing architectures [1], Infrastructure as a Service (IaaS), is shown in Figure 1.

The increasing requirement on cloud computing calls for the need of large numbers of large-scale data centers. However, operating large-scale data centers is both time and energy consuming. An estimated result from [2] predicts that data centers will have consumed 2 percent of the worldwide energy consumption by 2020. Particularly the energy consumed by data centers in U.S. is 1.5 percent of the total in 2006 and increases by 18% every year [3]. There is no doubt that it will bring significant burden on energy supply and cause environmental pollution, given that the consumption of one kilowatt hour electricity generates 0.555kg $CO_2$. With the gradual depletion and price escalation of traditional energy, the cost of operating data centers will surpass that of purchasing hardware. How to operate and manage data center in energy efficient way is an urgent problem.

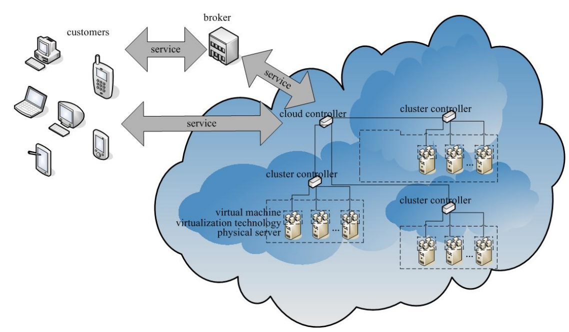


Figure 1. Cloud computing architecture.

The computing procedure power consumption, referred to as dynamic power consumption, constitutes the majority of energy consumption of data center without relating cool system. This paper investigates energy optimal associated with computing procedure using virtualization technology, which is a fundamental technique widely employed in cloud computing for resource sharing. The application of virtualization technology (such as Xen [4], VMWare [5], and Microsoft Virtual Servers [6]) consolidates os previously run on multiple physical servers to a smaller number of physical servers. That is, let different os environments exist on the same physical server with isolation from each other and underlying os, allowing an os environment migration from one physical server to another by live migration technology [7].Virtualization makes the utilization of data centers more flexible, secure, fault tolerant, manageable and economical. However, most existing researches of resource allocation concentrate on scheduling virtual machines (VMs) across physical servers with the objective of balancing the workload of data center to improve overall performance. Such approaches do not generally take into full consideration how to decrease energy consumption of data center. Moreover, cloud computing must ensure Service Level Agreements

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(SLAs). SLAs are established by negotiation between customers and providers, which specify stringent performance requirements such as response time, throughput, and so on. Therefore，operating data center in an energy efficient way while guaranteeing specified performance poses enormous challenges. In this paper, we formulate the energy efficiency virtual resource allocation for cloud computing as a multi-objective optimization problem which is then solved by intelligent optimization algorithm.

The remainder of the paper is organized as follows. The related work and our contributions are presented in Section 2. Section 3 introduces the related knowledge, notations and the formulation of system model. In Section 4, we present the solution and an example to illustrate the effectiveness of our approach. Section 5 depicts the simulation details and results. Finally, we conclude our work in Section 6.

## II. RELATED WORK

Operating data center in an energy efficient way is an emerging research topic in resource allocation of data center. There are several works applying different energy saving techniques proposed. Based on the scope of the role, existing researches can be roughly divided into two categories: server-level management and cluster-level management. The former focuses on energy saving in one physical server, and the latter optimizes energy of overall data center.

Server-level management mainly consists of the design of low voltage electronic component and Dynamic Voltage and Frequency Scaling (DVFS) technique. DVFS technique extends task complete alternation by reducing CPU frequency and supply voltage, thus maximally eliminating CPU idle cycle to save energy wasted. Based on the load request on server, some server-level management strategies dynamically regulated CPU frequency to save energy [8], [9], [10], [11]. Self-adaptation algorithm was proposed in [12] to regulate CPU frequency for energy saving. Although it can efficiently decrease the wasted dynamic energy of single machine, server-level management is incapable of avoiding static energy loss, i.e., inherent energy consumption of equipment.

Cluster-level management is mainly composed of two aspects, server turning on/off and virtual resource allocation strategy based on virtualization technology. Server turning on/off refers to shutting down the servers which are at idle state to avoid idle power wasting and turning on them when currently running servers are not able to bear the load. By using intelligent model to predict future load of data center, several works optionally tear down redundant servers to reduce overall energy consumption [13], [14]. Reference [15] proposed a solution scheme for energy saving derived from bin packing algorithm. In the research area of energy efficiently operating data center, server-level management and cluster-level management are not used alone. The research on combining both methods has made significant advancements [16], [17], [18], [19], [20]. Virtualization is one of the most fundamental characteristics of data center for cloud computing. Virtualization technology constructs virtual resource upon underlying hardware resource, maximizing the use of hardware. The researchers took advantage of virtualization technology features and proposed a variety of energy-saving schemes. Reference [21] and [22] consolidated VMs to run on as few physical machines (PMs) as possible. But they did not consider the capacity of PM due to the reason that PM performance decreases with the load rise. Reference [17] modeled virtual resource allocation problem as a problem of modified multi-dimensional bin-packing and find out an optimal performance and energy point. Unfortunately it did not propose an efficient algorithm to solve the problem. According to the contest on RAM, reference [23] dispatched VMs without considering other resources. Reference [24] allocated virtual resource with the objective of maximizing server utilization. But they lead to plenty of migration in scheduling process. The complexity of solving a large quantity of NP problems in [22] and [25] was unacceptable, although the researchers consolidated VMs in an energy efficient way. Heuristic algorithm was applied in [26] and [27] to search for optimized virtual resource allocation scheme by constructing cost function according to time delay, energy consumption, etc. Researchers developed a mixed integer programming (MIP) formulation to dynamically configure the consolidation of VMs in data center [28].

As far as we know, current researches on this topic are not able to efficiently decrease energy consumption of data center to ensure performance, or ensure SLAs of cloud computing service. In addition, the study on combining two methods, i.e., server-level management and cluster-level management, attracts less attention than it deserves.

Our contributions can be summarized as follows:

- We formulate virtual resource allocation problem as a Multi-objective Optimization Problems (MOP). Constraints functions represent the potential problems when VMs are scheduled across different PMs, such as QOS guarantee, capacity of servers, etc. Objective functions represent the number of servers used, total dynamic power and total utilization of servers used.
- We propose a high quality solution through the application of celebrated intelligent algorithm, non-dominated sorting genetic algorithm II (NSGA-II).
- The proposed approach demonstrates excellent performance in many experiments within a simulated environment modeling a virtualized data center of cloud computing.

## III. THE SYSTEM MODEL

This section gives a brief introduction on the related knowledge, notations and the formulation of system model.

### A. *Preliminary Knowledge*

This paper focuses on energy saving of computing procedure, i.e., CPU energy saving, which is the most part of energy consumption of data center without relating cool system. Thus understanding energy model of CPU is a critical premise for our work. The power consumption in CMOS circuits is organized with two parts: dynamic and static power. Static power is the inherent energy consumption. Therefore how to reduce dynamic power with performance guarantee is the most important.

The dynamic power consumption can be captured by

$$P = V^2 \times f \times C_{EFF}, \tag{1}$$

where $V$ , $f$ and $C_{EFF}$ denote the supply voltage, frequency and switched capacitance, respectively. Since $f$ is linearly proportional to $V$ [29], the dynamic power consumption of CPU can be given by

$$P = \alpha \times f^3, \tag{2}$$

where $\alpha$ is a coefficient. It is apparent that the time to complete a specific task is inversely proportional to CPU frequency. By multiplying both sides of Equation (2) by a time variable $t$, we have the energy consumption $E_{task}$:

$$E_{task} = \alpha \times \beta \times f^2, \tag{3}$$

where $\beta$ equals $f$ multiply $t$ and $\beta$ is a constant for specific task, namely,

$$E_{task} \propto f^2. \tag{4}$$

This indicates that lowering the supply voltage will reduce the energy consumption in a quadratic manner. However, lowering the supply voltage will slow down the time to execute a task. The DVFS technique reduces the supply voltage in conjunction with frequency, and then prolongs the execution time to eliminate the idle cycles of CPU to effectively save energy. This is the key point of DVFS. For convenience, we assume that each server in data center possesses DVFS technique which can adjust frequency continuously.

### *B. Notations*

Herein this paper $S = \{s_1, s_2, \ldots, s_m\}$ is the set of servers in data center of cloud computing. Assume that each server $s_j$ possesses DVFS technique, a maximum operating frequency $FS_j^{\max}$ and a minimum operating frequency $FS_j^{\min}$. Here, $FS_j^{\max}$ and $FS_j^{\min}$ are the frequency when server is at the highest and lowest performance state, respectively. With DVFS technique, the machine can regulate operating frequency between $FS_j^{\min}$ and $FS_j^{\max}$ smoothly. $V = \{v_1, v_2, \ldots, v_n\}$ is the set of virtual machines intended to be dispatched on servers in $S$. Each $v_i$ is characterized by a minimum $FV_i^{\min}$ frequency that it needs to keep designated performance.

To a data center of cloud computing, given a set of servers $S$ and a set of virtual machines $V$, we can construct an $n \times m$ matrix $X_{n\times m}$, where rows and columns represent VMs and servers, respectively. Element $x_{ij}$ in $X_{n\times m}$ is decision variable defined as follows:

$$\begin{cases} x_{ij} = 1, \textit{if VM } v_i \textit{ runs on server } s_j \\ x_{ij} = 0, \textit{otherwise}; \end{cases} \tag{5}$$

Decision variable $f_{ij}$ is the frequency of $v_i$ when scheduled on $s_j$. In this paper, using CPU frequency as the schedule factor instead of Core number or CPU utilization in many other works (e.g., [21], [17]) is based on its metrizability to better measure sharing of different VMs on a conventional machine. A function $U_j(X) = U_j(x_{1j}, x_{2j}, \ldots, x_{nj})$ is defined to identify whether a server is used or not:

$$\begin{cases} U_j(X) = 0, \textit{if } x_{1j}, x_{2j}, \ldots, x_{nj} \textit{ all equal } 0; \\ U_j(X) = 1, \textit{otherwise}; \end{cases} \tag{6}$$

### *C. Problem Formulation*

The problem formulation is a multi-constrained multi-objective optimization problem. It is given by the following mathematical form.

Minimize $\sum_{j=1}^{m} U_j(X)$ , $\sum_{j=1}^{m} (\sum_{i=1}^{n} f_{ij} x_{ij})^3$

and $\sum_{j=1}^{m} (\sum_{i=1}^{n} f_{ij} x_{ij} - FS_j^{\max})^2 \cdot U_j(X)$

(7)

subject to

$$x_{ij} \in \{0,1\}, \qquad i = 1,2,\ldots,n; j = 1,2,\ldots,m \tag{8}$$

$$\sum_{j=1}^{m} x_{ij} = 1, \qquad \forall i \tag{9}$$

$$FV_i^{\min} \le f_{ij} \le FS_j^{\max}, \qquad \forall i, \forall j \tag{10}$$

$$\sum_{i=1}^{n} f_{ij} x_{ij} \le FS_j^{\max}, \qquad \forall j \tag{11}$$

The objective function given by (7) consists of three aspects: 1) $\sum_{j=1}^{m} U_j(X)$ represents the objective to minimize the number of servers used to meet the request of schedule VMs as much as possible. This is the most principal aim due to the fact that powering down a server is much more energy efficient than any other energy saving techniques in server-level; 2) $\sum_{j=1}^{m}(\sum_{i=1}^{n} f_{ij}x_{ij})^3$ represents the objective to minimize the total power which VMs draw when executed on servers; and 3) $\sum_{j=1}^{m}(\sum_{i=1}^{n} f_{ij}x_{ij} - FS_j^{\max})^2 \cdot U_j(X)$ is based on a principle that makes good use of each server being used.

Constraint (8) is the schedule constraint. When $x_{ij} = 1$, a VM $v_i$ is scheduled on server $s_j$. Constraint (9) illustrates that a VM can execute on only one server. Constraint (10) is the performance restriction which keeps the VM performance above the acceptable level to guarantee QOS i.e., meeting the policies in SLAs of cloud computing such as response time while considering the capacity of server. Constraint (11) relates to the server capacity restriction, that is, the sum of frequency VMs need on a server must be less than the server`s maximum operating frequency.

The solution is thus given by decision variables $x_{ij}$ and $f_{ij}$.

## IV. SOLUTION

This section is devoted the description of our solution. In general, the objectives of multi-objective optimization problem collide with each other. It is impossible to achieve multiple objectives optimal simultaneously. The optimal solution in uni-objective optimization does not exist, which is replaced by pareto optimal solutions set. Given the fact that the number of pareto optimal solutions set is always huge even infinite, in practice some solutions are chosen according to practical needs. Traditional solutions for optimization are not suitable for such kind of problems. To tackle the problem faced, we introduce NSGA-II, which is one of the most outstanding evolutionary multi-objective optimization algorithms [30].

Based on NSGA-II, the entire procedure of the proposed virtual resource allocation strategy can be shown in Figure 2.

**Input:** the number of servers and virtual machines
**Output:** schedule scheme
**Begin**
Original population(solutions) OP is generated randomly;
No-inferiority sort is executed in OP;
Then new population is derived from OP through tournament selection, crossover and mutation;
**while** termination condition is not **do**
Combine new population and old population to a mate population which is then no-inferiority sorted;
Select several individuals to constitute a population by executing Crowd-distance sort on all no-inferiority front gained in last step;
New population is generated from the last population through duplicate, crossover and mutation;
**end**
**end**
A final solution will be chosen from feasible solutions to be optimal schedule scheme;
VMs are scheduled on servers according to the schedule scheme;
All relevant data of data center are compiled and recorded;

Figure 2. Procedure of virtual resource allocation strategy in pseudo code.

## V. SIMULATION PERFORMANCE AND ANALYSIS

In this section, we evaluate the performance of the proposed virtual resource allocation strategy through simulation.

### A. Simulation Condition

We have developed C++ simulation platform to evaluate the strategy proposed. In the platform, data centers with different numbers of servers are simulated. VMs with diverse characteristics are randomly generated to be scheduled running on servers. The number of servers varies from 20(a representation for small-size datacenters) to 100(for medium-size datacenters). NSGA-II is implemented in our simulation platform. For analysis, several significant assumptions are made in the simulation: 1) each server in data center with DVFS technique can regulate operating frequency continuously; 2) a potential difference of one unit across a CMOS circuit generates one unit CPU frequency, and altering this assumption will have no impact on the simulation results; 3) the static inherent power consumption accounts for 60 percent of total power consumption when a server is full loaded (referred to as static power consumption).

### B. Simulation Performance and Analysis

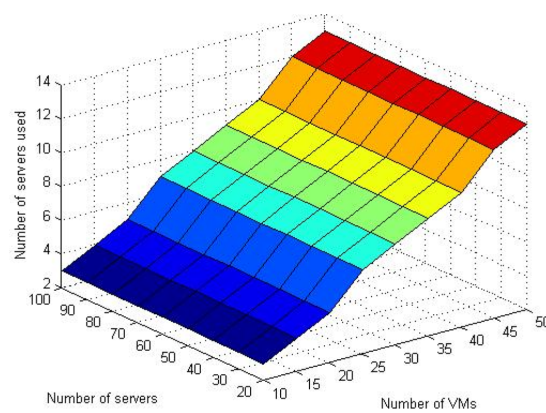


Figure 3. Number of servers used.

Figure 3 shows the number of servers to be used meets the VMs` request with different sizes of datacenters. The results indicate that, as the VMs` request increases, curve rises in a flat fashion. It is worth noting that the strategy we proposed uses as few servers as possible to construct VMs subject to the other objectives.

The total dynamic power consumption of all VMs generated on servers is presented in Figure 4. As shown in the figure 4, as the VMs` request increases, the curve of dynamic power consumption rises steadily which means the effectiveness of our strategy in controlling total dynamic power consumption increase even when the inputs (the number of servers-VMs) become more complex. The total utilization of servers being used is reported in Figure 5. As shown in the figure 5, the surface presents a state of low range rise with several winding up and down. It suggests that

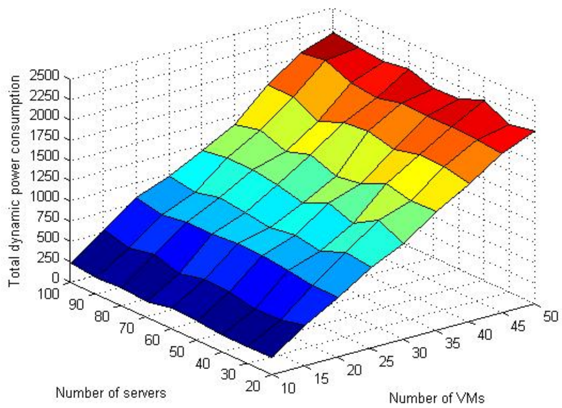


Figure 4. Total dynamic power consumption.

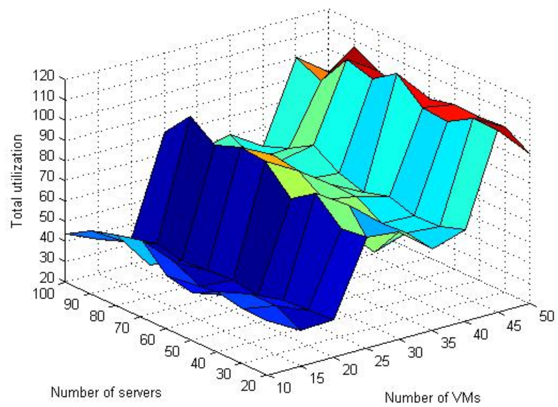


Figure 5. Total utilization.

the strategy performs well in some inputs. And as the inputs become more complex, the performance of controlling the total utilization decreases slightly. However, on the whole, the cure of total utilization is maintained at a low level, which means the strategy makes good use of every server being used.

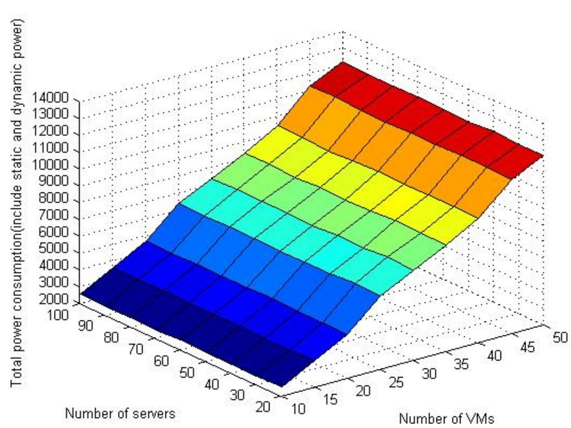


Figure 6. Total power consumption (including static and dynamic power).

The overall power consumption of the datacenter after schedule according to the schedule scheme out of resource allocation strategy is depicted in Figure 6. It is evaluated by pulsing total dynamic power consumption presented in Figure 4 and total static power consumption. We can observe that as the inputs become more complex, the total power consumption amplitude is smooth instead of an explosive growth in other proposals.

## VI. CONCLUTION AND FUTURE WORK

This paper studies the issue of operating data center in an energy efficient way while guaranteeing specified performance. We formulate the problem as a multi-constrained multi-objective optimization problem, which is then solved by one of the most outstanding evolutionary multi-objective optimization algorithms NSGA-II. In order to demonstrate the advantages of our strategy, we perform simulations in a variety of conditions and evaluate the quality of the strategy we proposed in a simulation platform. The results prove that the strategy can successfully generate schedule scheme of different numbers of servers-VMs with diverse characteristics in a reasonable time period.

In the future work, we try to find better ways to solve the MOP proposed, and we try to extend the strategy by taking into consideration more complex situations, such as cost of server turning on/off. Moreover we will compare the approach with other related researches in this area and validate the practicability of our strategy in a real cloud computing leveraging virtualization technology such as XEN.

## ACKNOWLEGMENT


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