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Genetic algorithm based optimization technique for power management in heterogeneous multi-tier web clusters

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ABSTRACT

As the web applications are becoming more sophisticated and their processing power is gradually increasing, the most serious drawback now days is the power management. Current clusters for various applications are designed to handle peak loads, where all servers are equally utilized. In practice, peak load conditions barely happen and clusters are most of the time underutilized. This paper deals with the problem of optimizing the performance (in terms of execution time) of a multi-tier system and also reducing the power consumption of the servers. To achieve these objectives, the Genetic algorithm based optimization technique is applied on a three-tier web cluster system. This technique has proved to be successful in reducing the power consumption and increasing the performance of the system. The experimental results of this technique are compared and analyzed with the experimental results of the Generalized Benders Decomposition technique.

Keywords: Genetic algorithm, Heterogeneous, Multi-tier cluster, Power, Server.

1. INTRODUCTION

Complex web applications are usually served by the multi-tier web clusters. For example, a typical web cluster consists of web service tier, transaction tier and database tier. Every tier performs different roles in different applications. With the growing cost of energy, researchers are paying more and more attention towards the energy efficiency [1],[2],[3]-[5],[8]. These web servers are often significantly over-provisioned in order to meet the target response delay constraints even under the peak loads. This leads to incur low energy efficiency for those clusters. Hence, it is desired to increase performance per unit of energy. Many power management mechanisms have been proposed for multi-tier clusters [9]-[14]. But most of them have focused solely on homogeneous clusters [22]-[24]. However, clusters are almost invariably different in terms of their performance, capacity and power consumption. Most of today's data centers comprise of heterogeneous servers because many misbehaved or failed servers get replaced with different ones. The heterogeneity also arises from the fact that when a data center undergoes any upgrades, it is technically impossible to replace all the servers due to the size of the data centers. Therefore, new servers with different specification are added to the old ones. The heterogeneous architecture brings new challenges to power management of clusters. In the homogeneous clusters, we only needed to know how many servers are turned on and which frequency level they run at. But in heterogeneous clusters, we also need to decide that which server should be powered on or off. Furthermore, the workload distribution is not a trivial task in the heterogeneous clusters, which is used to be not that difficult in homogeneous clusters. Remaining paper is organized as Section 2 includes the related work. Section 3 describes the system model. Section 4 explains about basic working of the genetic algorithm. Section 5 represents the pseudo code of the program. Section 6 shows the experimental results and simulation. Section 7 shows the conclusion of the work implemented.

2. RELATED WORK

In order to decide the best and fruitful power management technique for this multi-tier web cluster model, the below given literature review was surveyed.

2.1 Power management for multi-tier clusters

Horvath et al. [5] presented a DVS control algorithm that minimizes power consumption in a server pipeline subject to end-to-end latency constraints. Their implementation had two components: an Apache module to measure the end-to-end latencies, and a daemon on each server that measured its CPU utilization, ran the feedback controller. Horvath et al. [6] stated an energy management policy for reconfigurable clusters running a multi-tier application, exploiting DVS together with multiple sleep states. They developed a theoretical analysis of the corresponding power optimization problem and designed an algorithm around the solution. Moreover, they rigorously investigated the selection of the optimal number of spare servers for each power state, a problem that had only been approached in an ad-hoc manner in current policies. Choi et al. [1] identified two kinds of power budgets (i) an average budget to capture an upper bound on long-term energy consumption within that level and (ii) a sustained budget to capture any restrictions on sustained draw of current above a certain threshold. Using a simple measurement infrastructure, they derived power profiles—statistical descriptions of the power consumption of applications. Based on insights gained from detailed profiling of several applications - both individual and consolidated, they developed models for predicting average and sustained power consumption of consolidated applications. Govindan et al. [15] explored a combination of statistical multiplexing techniques to improve the utilization of the power hierarchy within a data center. At the highest level of the power hierarchy, they employed a controlled under provisioning and over-booking of power needs of hosted workloads. At the lower levels, they introduced the novel notion of soft fuses to flexibly distribute provisioned power among hosted workloads based on their needs. Rao et al. [8] modeled the problem as a constrained mixed-integer programming and proposed an efficient solution method. The authors converted the approximated linear programming to a minimum cost flow problem for deriving fast and efficient solution. A fast strongly polynomial-time solution algorithm for general incapacitated minimum cost flow problems was described. Schranzhofer et al. [13] stated that task assignment and processing unit allocation are key steps in the design of predictable and efficient embedded systems. Given the execution modes of applications, they proposed a methodology to compute a task to processing element mapping, such that the expected average power consumption was minimized.

2.2 Power management for homogeneous clusters

Liu et al. [22] proposed an Energy Efficient clustering based Scheduling Algorithm for Parallel tasks on Homogeneous DVS-Enabled Clusters (ECSTD) that helps to improve both performance and energy efficiency in homogeneous clusters. Zhao et al. [23] proposed an energy-efficient Dependency-based task Grouping (DG) method to assign parallel tasks under precedence constrains to multi-core processors which helps in achieving the goal of optimizing performance and energy efficiency in homogeneous clusters. Zong et al. [24] proposed two energy-efficient duplication-based scheduling algorithms that are Energy-Aware Duplication (EAD) scheduling and Performance-Energy Balanced Duplication (PEBD) scheduling to optimize performance as well as energy efficiency.

2.3 Power management for heterogeneous clusters

Rusu et al. [12] stated a cluster-wide QoS-aware technique that dynamically reconfigures the cluster to reduce energy consumption during periods of reduced load. Moreover, they also investigated the effects of local QoS-aware power management using Dynamic Voltage Scaling (DVS). For validation, they described and evaluated an implementation of the proposed scheme using the Apache Web server in a small realistic cluster. Al-Daoud et al. [9] proposed the power-aware LPAS policy for heterogeneous systems. The power-aware LPAS policy requires solving two allocation linear programming (LP) problems. The first LP does not take power consumption into account. It is the same LP that is used in the other LPAS-related policies. This LP is solved for the purpose of obtaining the maximum capacity of the system. Wang et al. [16] addressed the challenge of power management in Heterogeneous Multi-tier Web Clusters. They applied the Generalized Benders Decomposition (GBD) to decompose the global optimization problem into small sub problems. This algorithm achieved the optimal solution in an iterative fashion. In this paper, Genetic Algorithm based optimizing technique was implemented and analyzed to increase the performance and reduce more power consumption in heterogeneous multi-tier web clusters. The proposed technique showed promising results.

3. SYSTEM MODEL

3.1 Web cluster model

I studied the typical three-tier web clusters. The first tier depicts web service to the client, the second tier depicts the business logic and the third tier depicts the database tier as shown in figure 1.

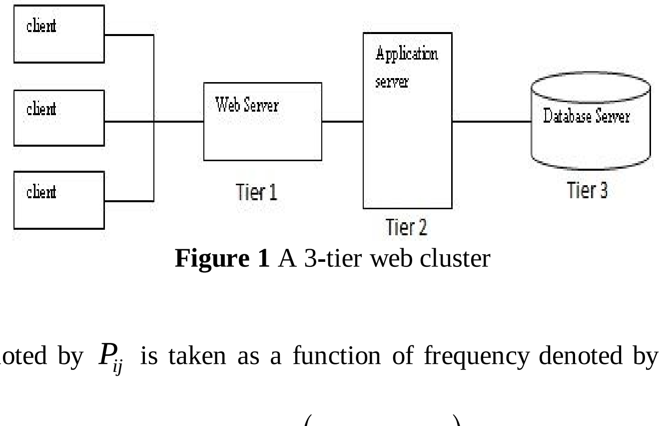

Figure 1 A 3-tier web cluster

3.2 Power model

The power consumption denoted by P_{ij} is taken as a function of frequency denoted by f [16]. P_{ij} is approximated with the following equation:

$$P_{ij} = s_{ij}\left(X_{ij} f_{ij}^{z} + Y_{ij}\right)$$

Here,

s_{ij} represents the server on/off state.

X_{ij} represents the positive constant indicating the effect of frequency f.

Y_{ij} depicts the constant power consumption.

z represents the number of tiers.

4. GENETIC ALGORITHM

A genetic algorithm is a search technique that is used in computing to discover the true or approximate solutions for the optimization and search problems. The evolution starts from a population of randomly produced individuals and occurs in generations. In each generation, the fitness function of each individual in the population is calculated. Then two or more individuals are selected on the basis of their fitness function from the current population. The higher the fitness function, the more are the chances of being selected. After that those individuals are modified or recombined and possibly mutated to form a new population. This goes on until an optimal solution is found. That new population is then further used for the next iteration of the algorithm. The basic working of genetic algorithm is shown in figure 2.

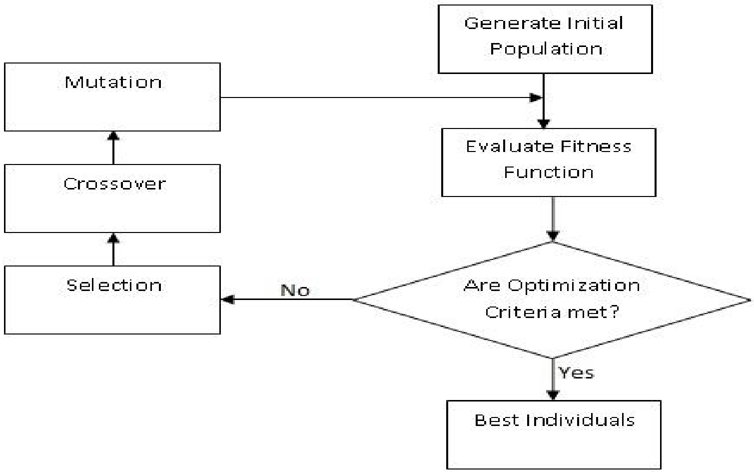

Figure 2 Flowchart of GA

5. PSEUDO CODE

```
Initialize; servers, simulation time
Do
Check.load.value
Checl.power.value
Check.jobs.value
End
Do
Check job specification
Value.no.of jobs
Value.total jobs
End
for k=p:jobs_per_server
job_load_per_server(i,k)=j_id(n);
job_power(i,k)=j_pow(n);
job_time(i,k)=j_time(n);
do
check= completion list
jobs done
power consumed
while
check execution time
if jobs_completed_per_server < jobs_per_server
break
end
```

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initialize; time t := 0; population P (t);
evaluate fitness function
check termination criteria;
if criteria meets,
check jobs done
check completion list
check power list
check total time consumed
break
end

6. RESULTS AND SIMULATION

This section presents the results of the proposed technique with comparison to Generalized Benders Decomposition technique. MATLAB is used for implementation of the algorithm and simulation of clusters. The program runs on Intel(R) core i3 CPU 2.27 GHz and 3G RAM. Servers are taken randomly considering following parameters:-

Table 1: Server Parameters

S. No.	Parameters	Values
1.	Server id	s_id
2.	Server load	s_load
3.	Server state	s_state
4.	Server power	s_power

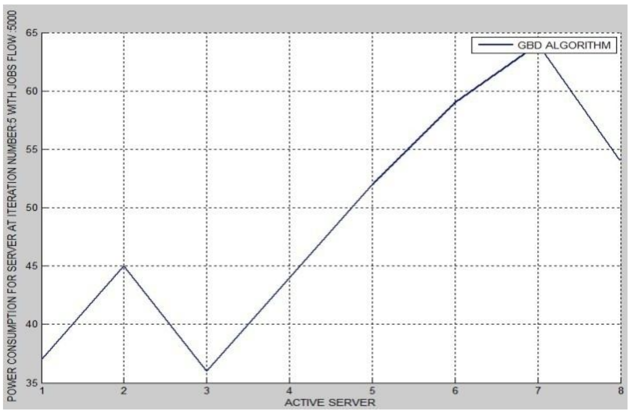

Figure 3 Power consumption with respect to active server using GBD

Figure 3 shows the power consumption with respect to number of active servers using GBD.

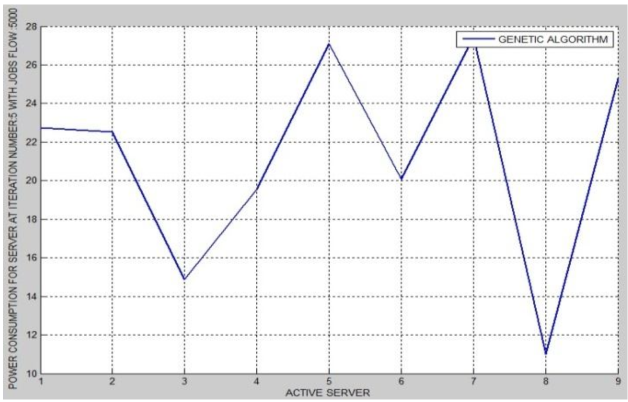

Figure 4 Power consumption with respect to active server using GA

Figure 4 shows the power consumption with respect to number of active servers using GA.

Table 2: Power Consumption wrt active servers

Job Requests	GBD, Active Server = 8	GA, Active Server = 9
5000	65 W	28 W

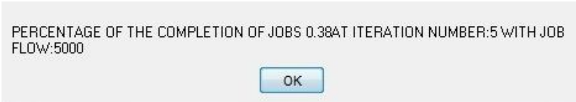

Figure 5 Job completion percentage using GBD

Figure 5 shows the percentage completion of jobs with respect to number of iterations and results that at 5^{th} iteration the completion job percentage is 0.38 with 5000 job requests.

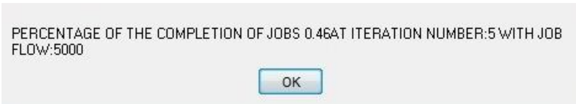

Figure 6 Job completion percentage using GA

Figure 6 shows the percentage completion of jobs with respect to number of iterations and results that at 5^{th} iteration the completion job percentage is 0.46 with 5000 job requests.

Table 3: Percentage of job completion

Jobs requests	GBD	GA
5000	38 %	46 %

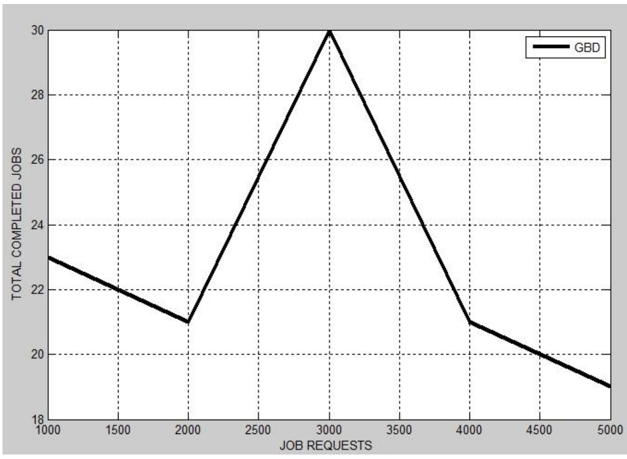

Figure 7 Total completed jobs with GBD

Figure 7 shows the total number of jobs completed with respect to the number of requested jobs using GBD which are 30 jobs in number.

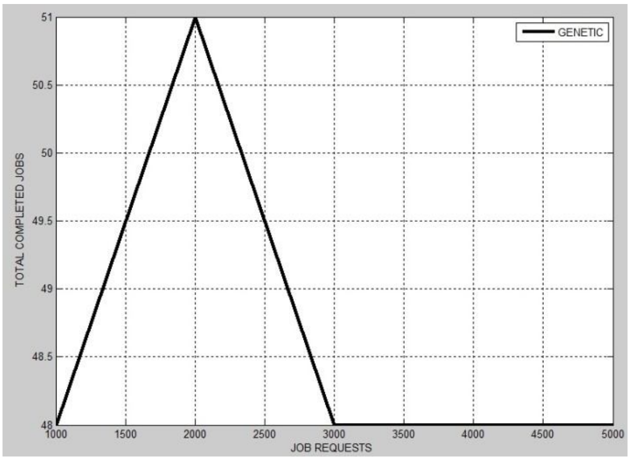

Figure 8 Total number of jobs completed with GA

Figure 8 shows the total number of jobs completed with respect to the number of requested jobs using GA which are 51 jobs in number.

Table 4: Total number of computed Jobs

Jobs requests	GBD	GA
5000	30	51

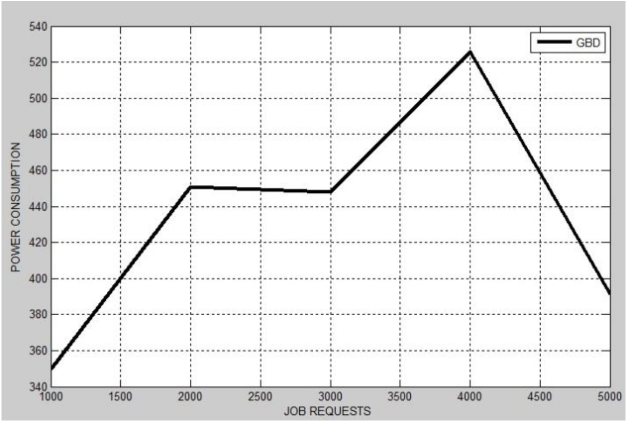

Figure 9 Total power consumption with GBD

Figure 9 show the total power consumed using GBD which is 525 W with respect to the number of job requests.

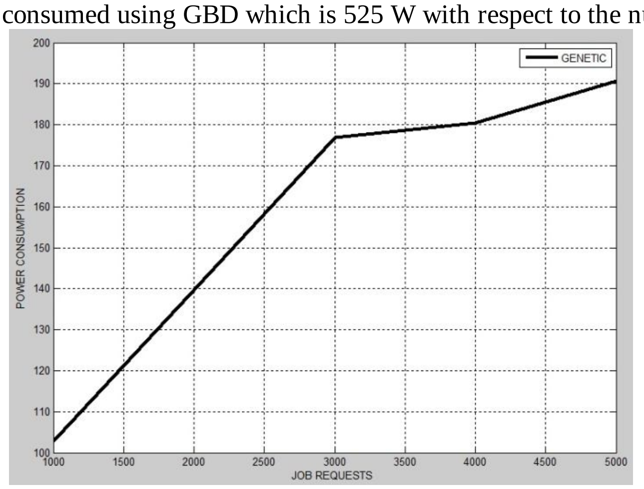

Figure 10 Total power consumption using GA

Figure 10 shows the total energy consumption using GA which is 192 W with respect to the number of requested jobs.

Table 5: Total power consumption

Jobs requests	GBD	GA
5000	525 W	192 W

7. CONCLUSION AND FUTURE WORK

This paper deals with the performance (in terms of execution time) and power management adversity for the heterogeneous multi-tier web clusters. MATLAB simulation tool was used in order to perform the implementation. In this paper, I first designed and analyzed the performance and power consumption results of the Generalized Benders Decomposition (GBD) technique. The experimentation results showed that GBD reduced 38% of the power consumption by the servers. In order to increase the performance and reducing more power consumption, Genetic Algorithm optimizing technique was implemented and analyzed. The proposed technique showed promising results, thereby reducing more power consumption i.e. 46% as compared to GBD technique. The experimentation results are shown in the form of graphs and tables developed by the MATLAB simulation tool. Further research can be performed in order to increase the performance and reduce the power consumption. Better problem optimizing techniques can be applied. Better energy efficiency or scheduling techniques can be inculcated.

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