A Framework of Dynamic Power Management for Sustainable Data Center

San Hlaing Myint, and Thandar Thein

Abstract—Sustainability of cloud data center is to be addressed in terms of environmental and economic effects. Cloud computing is a new opportunities to deploy sustainable solutions and advance their services upon that platform. Energy efficiency deals with performing the same tasks as before while consuming less energy, resulting in lower costs. Energy efficiency helps reduce the world carbon emissions, a key factor to attain a greener environment. The environmental impact of data centers is very significant in green environment because of their enormous amount of power consumption and carbon dioxide emissions. Energy efficiency approaches, such as dynamic power management (DPM), become a critical issue in sustainable data center environment while it is important to ensure to meet service level agreement (SLA).

The aim of this paper is to discover the energy efficient power management approach for cloud data center. Sustainable data centre framework (SDC) is proposed as a sustainable solution for next generation data center. In proposed framework, machine learning based resource prediction is performed for handling dynamic workload nature. As a consequence, future power demand and CO₂ emission is estimated to provide dynamic power management process. And then we explore the energy efficient dynamic power management approach for proposed SDC. On the other hand, SLA violation is considered as the one of sustainable factors. Finally we developed a simulation environment and evaluated the proposed approach to prove how does our proposed DPM effective on SDC framework.

Keywords—Carbon dioxide Emission, Energy Efficient Cloud Data Centers, Service Level Agreement, Sustainability.

I. INTRODUCTION

SUSTAINABILITY science seeks real world solutions to sustainability issues and aims to break down artificial and outdated disciplinary gaps between the natural and social sciences through the creation of new knowledge and its practical application to technology transfer and decision making (Clark & Dickson, 2003; Palmer et al. 2005; Weinstein et al. 2007). Public concern about environmental sustainability has grown steadily rapidly in recent years. Nowadays IT farms become a main focus area of sustainability. Especially modern data center consumes enormous amount of power consumption. As a consequence, Gartner estimation [4] found that IT is responsible for about 2% of global greenhouse gas emissions in 2007, about as much as the aviation industry, the energy and CO₂ impacts of data centers are expected to more than double by 2020. This concern, coupled with increasing government interest in regulating data center resource consumption, is resulting in a new approach to management of data centers.

Some technologies and means in data centre infrastructures are investigated to aid cloud computing to save more energy and having less impact on the environment. Dynamic power management (DPM), dynamic voltage management (DVFS) and virtualization are popular energy efficiency approach and state of the art challenges for sustainable data center environment.

However, there are many opportunities for greater efficiency through integrated design and management of data center components. This paper focuses on many aspects of sustainability of modern data centers which include environmental impact, economic effect, minimizing energy consumption, reducing CO₂ emission, and efficient processing and utilization of computing infrastructure. On the other hand, satisfaction of QoS requirements specified by users via Service Level Agreements (SLA) is an important consideration factors. Proposed sustainable data center design is an effective solution for minimizing SLA violation, energy consumption and carbon emission. The core idea of three server pools design (Active, Sleep, Shutdown) can achieve server consolidation strategy and efficient dynamic power management solution while mediating the SLA violation effectively. Dynamic power management is the main concern of energy efficient cloud data centers. Finally we evaluate SLA violation and energy consumption by comparing traditional and cloud data centers to figure out which one is more recommended to be deployed.

II. PROBLEM STATEMENTS

The core idea of this paper is to solve power wasting overprovision problem which is happened because an idle server burns almost as much as power as a busy server. The comparison of idle and busy state power consumption of Intel Xeon server and CPU is shown in Table 1 and 2. As compare with 350.6 watt Intel Xeon X5570 server, an idle server can consume 153.8 watt. While a 100% utilization CPU (Intel Core i5-2300) consume 51.1 watt, it consumes 4.5 watt at idle state [2, 5].

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Typically, the server components experience non-uniform workloads during the course of their operation. Future workload of server components can be predicted, with some degree of uncertainty, using probabilistic techniques on the basis of the recent workload history. The characteristics of efficient power management techniques are as follow:

- It can be implemented in software, hardware, firmware or VM.
- It is limited to a component, server, cluster or data center.
- It is based on a local or global optimization metric.
- It has local or global resource distribution management.

Dynamic Power Manager or Autonomic Power Manager (APM) is a framework that dynamically powers on/off electronic devices after predicting the future workloads [8, 10, 12]. Backend of the dynamic power management. Virtualization is implemented in both the server and switch domain but with different objectives. Server virtualization usually achieves energy efficiency by sharing limited resources among different applications. However, sharing the same physical resources that previously would have been dedicated to one physical machine comes at a cost. Virtualization is the one of the most effective ways toward energy efficiency. Virtualization is the most adopted power management and resource allocation technique used by the data center operators [1]. This work is not focused on virtualization technology.

### IV. FRAMEWORK OF DYNAMIC POWER MANAGEMENT FOR SUSTAINABLE DATA CENTER

Dynamic power management for sustainable data center is presented in Figure 1. It consists of infrastructure design and management environment.

![Fig. 1 Dynamic Power Management for Sustainable Data Center Architecture](image)

In the infrastructure design, physical servers are group into three server pools (Active pool, Sleep pool and Shutdown pool) which have three different states such as running state, sleeping state and power off state respectively. The data center

<table>
<thead>
<tr>
<th>INTEL XEON SERVER POWER CONSUMPTION</th>
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<tbody>
<tr>
<td><strong>Intel Xeon Server</strong></td>
</tr>
<tr>
<td></td>
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<tr>
<td>X5570, Dual-Core</td>
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<tr>
<td>X5670, Quart-Core</td>
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<td>E5520, 2 Quart-Core</td>
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<table>
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<tr>
<th>INTEL CORE i5 PROCESSOR POWER CONSUMPTION</th>
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<tr>
<td><strong>Intel Xeon Server</strong></td>
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<td>Core i5-2300</td>
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<td>Core i5-2400</td>
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<td>Core i5-2500</td>
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In such scenarios, in order to save power idle servers are needed to turn off. Most existing research considered two policies (On/Off). In this case, turning servers off have a setup cost to later turn them back on. This is the main problem for SLA which guarantee for waiting delay time. In order to meet delay guarantee, two policies are not enough. We need to setup new policy to mediate this problem. Sleep mode state, with shorter setup time and lower power requirement, is a good solution to overcome this problem. It is not only to solve overprovision problem but also mediate SLA violation. On the other hand, it can save cost of wasted power consumption and degrade environmental impacts of carbon dioxide emission.

### III. ENERGY EFFICIENT TECHNIQUES

Energy efficiency becomes the main concern for data center design consideration in green environment. Without much overhead, many energy efficiency techniques can be applied at the data centers. These include the Dynamic Power Management (DPM) or device reduction, Dynamic Voltage Frequency Scale (DVFS), Virtualization and the improvement of port, server, storage, cooling, and electricity supply efficiency [9]. Among them, DPM, DVFS and virtualization are the state of the art energy efficiency techniques. Some authors classify DVFS under DPM techniques [15]. In this work, DPM is emphasized to provide capacity management of cloud data center.

**A. Dynamic Power Management**

The basic concept of all the energy efficiency techniques is that service providers built data centers with redundant resources to meet QoS requirements and performance guarantee which causes overprovision problem. DPM is a set of techniques in which server equipments are dynamically power off according to the current load. The number of active server components is restricted to a minimum while conforming to the required performance and QoS criteria.
is composed of high performance heterogeneous physical servers which supported virtualization technology and serve cloud services to cloud users. This system architecture covers energy consumption problem, carbon dioxide emission problem and SLA violation problem due to resource over provisioning in the data center to keep high performance guarantee.

In management environment, it includes resource demand predictor, carbon dioxide emission estimator and power manager, resource manager and SLA evaluator.

A. Resource Demand Prediction

Resource usage demand of future workloads is predicted by using machine learning (ML) techniques. We focus on CPU resource usage demand in this work. The processing steps are: data standardization, feature selection, model generation and model evaluation process. Data standardization process consists of subtraction the value from its average value and divides the result by its standard deviation. Feature selection is conducted as a preprocessing step in machine learning based prediction process and is effective in reducing dimensionality, removing irrelevant data, increasing learning accuracy, and improving result comprehensibility. Model generation process is performed to develop a set of models and choose the best one according to different parameters selecting the more accurate result.

Finally model evaluation process is conducted by comparing different Machine Learning algorithms in order to choose the (approximately) best one. Power machine learning algorithms such as Bagging, M5P and REP Tree are used for model evaluation process. In order to evaluate the prediction quality of experiment machine learning algorithms, two metrics: correlation coefficient and mean absolute error (MAE) are calculated. We conducted this evaluation process on three workload traces: Parallel Workload Archives (SHARCNET & OSC) and Google Cluster Workloads. The prediction accuracy of ML algorithms are shown in Figure 2 and 3. Weka 3.6 toolkit is used for model evaluation process [6].

**Correlation Coefficient**: This metrics is based on the standard correlation coefficient and measures the extent of linear relationship between predicted $\omega^*$ and actual $\omega$ values. It is a dimension less index that ranges from -1 to 1 with 1 corresponding to ideal correlation. The correlation coefficient C is given by:

$$C = \frac{\text{cov}(\omega - \omega^*)}{\sigma_\omega \delta_\omega}$$  \hspace{1cm} (1)

Where $\text{cov}(\omega, \omega^*)$ the covariance between the predicted and the actual values is, while $\sigma_\omega$ and $\delta_\omega$ are their respective standard deviations.

![Fig. 2 Correlation Coefficient over Three Workload Traces](image)

**Mean Absolute Error** : MAE, is the average of the difference between predicted and actual value in all test cases; it is the average prediction error. MAE can be calculated as follow:

$$MAE = \frac{\sum \mid \omega - \omega^* \mid}{N}$$  \hspace{1cm} (2)

Assuming that the $\omega$ is actual CPU usage observed by Job, and $\omega^*$ would be expected CPU usage of Job.

![Fig. 3 Mean Absolute Error (MAE) over Three Workload Traces](image)

According to Figure 2, we can clearly see that correlation coefficient scores of Bagging algorithm are 0.94, 0.894 and 0.9033 respectively over three workload traces. In Figure 3, Bagging algorithm has least MAE error compared with other two algorithms over different workload traces. We found that Bagging provides highest prediction accuracy compared with other algorithms over different workload traces. Prediction accuracy of Bagging have 92% and above, and it’s MAE nearly zero over all workload traces.

B. Carbon Dioxide Emission Estimation

To facilitate energy efficient computing, the information about the CO$_2$ emission rate is needed to provide. The power consumption of a physical machine can be estimated by a linear relationship between power consumption and CPU
utilization. And also the CO₂ emission rate is directly proportional with power consumption respectively. CO₂ emission of a server is calculated base on estimated power consumption. The power consumption and CO₂ emission of a server is calculated by using the following equations.

\[ P_{srv} = \sum_{t=1}^{T} P_{ui} + (P_{max} - P_{ui}) \times \frac{u}{100} \]  \hspace{1cm} (3)

Where \( P_{srv} \) is the power consumption of a server at \( u\% \) CPU utilization of given workload. \( P_{ui} \) is the power consumption of \( u\% \) CPU utilization of given workload. \( P_{max} \) and \( P_{ui} \) are power consumption of maximum CPU utilization and idle, respectively.

\[ CO_2_{P_{srv}} = y \times CO_2_{P_{srv}} \]  \hspace{1cm} (4)

Where \( y \) is CO₂ emission rate. CO₂ emission of a server at \( u\% \) CPU utilization. \( CO_2_{P_{srv}} \) is the CO₂ emission of a server at \( u\% \) CPU utilization of given workload.

The estimated power consumption and CO₂ of Google workload traces are shown in the following Figures 4 and 5. We found that power consumption, CO₂ emission and CPU consumption are linearly related to each others.

**C. Power Manager**

Power Manager manages the power consumption of three pools of servers according to predicted resource demand of future workloads. In order to conduct power management process, dynamic power management (DPM) algorithm is proposed as shown in Figure 6. It determine which servers should be turn off when they are idle. In this managing process, there are many complicated problems for transferring host from one pool to another. When it is needed more resource according to predicted future workload demands, the number of host needed to server is pulled from other pools. When they are not needed, it is needed to put them back to their mother pool. We assumed all host in Active Pool is running on every time and hosts in the last pools (Sleep Pool and Shutdown Pool) will be running when it is needed. We develop dynamic power management algorithm as an energy efficient technique that dynamically change power state of servers after predicting the future workloads.

The basic concept of algorithm is to select a set of hosts for resource allocation. We assumed that jobs are processed in batch mode and batch size is 1 minute. If required number of hosts are more than current servers, the system will turn on \((T^* - T^{**})\) servers which are in sleep mode or shutdown mode. If required servers are less than current servers, the system will turn off \((T^* - T^{**})\) hosts to save energy. According to proposed design concept, all hosts in Active Pool are running every time. We assumed that the total number of host in Active Pool is minimum number of host to serve and the total number of hosts in three pools is maximum number of host to serve.

**Algorithm : Dynamic Power Management Algorithm**

Input: \( S_{ij} \): a metric include system information about all host placed in each pool

\( C_{ij} \): a metric include information about current assigned hosts

Output : Power on/off decision, Updated \((S_{ij}, C_{ij})\)

\( T = \text{Null} \);

For ( \( i = 1, 2, 3 \ldots, a \) ) // for all jobs in job queue

Fetch all Jobs form job queue // Denote it processes in Batch mode

Calculate the required number of CPU (\( T^* \))

Calculate the number of Current used CPU (\( T^{**} \))

\( T = T + T^* \);

If \( T = T^{**} \),

\( T = T^{**} \);

Else if \( T < T^{**} \)

\( N = T^{**} - T^* \),

Select N servers // in sleep pool or shut down pool to sleep

and

\( T = T - N \);

Update \((S_{ij}, C_{ij})\)

Else

\( N = T^* - T^{**} \),

Select N servers // in server pools to turn on

\( T = T + N \);

Update \((S_{ij}, C_{ij})\)

End if

Go to resource allocation algorithm to assigned \( T \) servers

Return Updated \((S_{ij}, C_{ij})\)

**Fig. 6 Dynamic Power Management Algorithm**

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Fig. 4 CPU utilization and Power Consumption (Google)

Fig. 5 CPU Utilization and CO₂ Emission (Google)
D. SLA Evaluator

SLA evaluator checks SLA violation with energy consumption reduction while maintaining QoS requirement and performance guarantee. In this work, our goal is to guarantee that setup time for restarting host is fewer than 70% and CO₂ emission is fewer than 60% of normal data center.

According to power saving aspects, more turning off server leads to increase in waiting time for jobs. This problem is mediated by the existence of sleep mode, with shorter setup time. We define SLA violation risk of waiting time as follow:

$$V_{SLA} = \frac{T_{off} + T_{sleep}}{\alpha \cdot T_d}$$ (5)

Where $\alpha$ is the waiting factor, and $T_d$ denotes Average Duration Time. $T_{off}$ and $T_{sleep}$ are average power off server setup time and average sleep server setup time respectively. $T_d$ is calculated based on Equation 4.

$$T_d = \frac{\sum_{i=1}^{N} n_i \cdot d_i}{\sum_{i=1}^{N} n_i}$$ (6)

Where $d_i$ is the duration required by request $i$. $N$ is the number of request waiting in queue and $n_i$ is the number of resources. $T_{off}$ and $T_{sleep}$ are calculated as follow:

$$T_{off} = \frac{\sum_{i=1}^{N} n_i \cdot ST_{off}}{\sum_{i=1}^{N} n_i}$$ (7)

$$T_{sleep} = \frac{\sum_{i=1}^{N} n_i \cdot ST_{sleep}}{\sum_{i=1}^{N} n_i}$$ (8)

Where $ST_{off}$ and $ST_{sleep}$ are denoted as setup time of a server.

V. RELATED WORKS

Nowadays in the modern data center environment, service provider and user much more about reaching a sustainable strategy for their operations. The researchers proposed a sustainable data center that replaces conventional resource delivery models with a framework centered around the supply and demand side management of all data center resources including IT, power and cooling [13].

Most of data centers are suffering from energy wastage of underutilized or idle resources. Many researchers explored energy efficient techniques for saving energy consumption. Dynamic Power Management (DPM) is an energy efficiency technique for reducing power dissipation in systems by slowing or shutting-down components when they are idle or underutilized[15].

In [6], researchers introduced two main power states: active (DVFS) and inactive (Idle/sleep) of power interface (ACPI) which is applied in data center and devices for energy efficiency. In active mode, the device adjusts its power due to its performance whereas the operation is ceased due to power demand in inactive mode. Khargharia et al. [8] have proposed a theoretical framework for optimizing the per watt performance of a data center at each level of hierarchy—cluster level, server level and device level. The Autonomic Manager (AM) works in four phases, viz. monitoring, analysis, planning, and execution wherein each phase is dependent on the previous workload history. Gong et al. [3] have studied the issue of energy-aware server provisioning and load dispatching for connection-intensive applications. They have used real trace data from a data center hosting Windows Live Messenger application. Three server provisioning algorithms are described: hysteresis-based provision, forecast-based provision and short-term load forecasting. The server load provisioning algorithms are tested on a testbed of 60 connection servers and a load dispatcher with real data center traces.

In this work, we try to prove that proposed sustainable data center design has better energy efficiency than traditional data center. The core idea of sustainable data center design is the major concern of this research. DPM and Optimal resource allocation algorithms are developed by extending these concerns. DPM algorithm is proposed as a sustainability aspect of modern data center.

VI. SIMULATION ENVIRONMENT

<table>
<thead>
<tr>
<th>Model</th>
<th>speed</th>
<th>Number of CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xeon L5506</td>
<td>2.23 GHz</td>
<td>4</td>
</tr>
<tr>
<td>Xeon LC3528</td>
<td>1.73 GHz</td>
<td>2</td>
</tr>
<tr>
<td>Xeon EC3539</td>
<td>2.13 GHz</td>
<td>4</td>
</tr>
<tr>
<td>Xeon E5506</td>
<td>2.13 GHz</td>
<td>2</td>
</tr>
<tr>
<td>Xeon E5507</td>
<td>2.13 GHz</td>
<td>2</td>
</tr>
<tr>
<td>Xeon L5520</td>
<td>2.27 GHz</td>
<td>4</td>
</tr>
<tr>
<td>Xeon L5530</td>
<td>2.4 GHz</td>
<td>4</td>
</tr>
<tr>
<td>Xeon E5502</td>
<td>1.87 GHz</td>
<td>2</td>
</tr>
<tr>
<td>Xeon E5503</td>
<td>2 GHz</td>
<td>2</td>
</tr>
</tbody>
</table>

In this work, we developed a java simulation platform for managing three server pools and batch jobs in a data center. Three server pools are built as Active pool, Sleep pool and Off Pool. Each pool consists of a hundred heterogeneous Intel Xeon Servers. System specification of heterogeneous servers is described in the following table 3. All servers supported virtualization technology. We use batch mod processing for inputting jobs. Each batch job contains about 150 jobs with different CPU resource utilization which is assumed about 1 minute time interval for batch size.

VII. EVALUATION ON SIMULATION ENVIRONMENT

In this experimentation, we compare power consumption and CO₂ emission of sleep mode and active mode on heterogeneous servers as shown in Figure 7 and Figure 8. Experimental results show sleep mode power consumption is very close to zero power while active mode uses their maximum power consumption. It can effectively reduce power consumption of idle servers and also in carbon dioxide emission. On the other hand, sleep mode reduce the setup time.
presented the accuracy of selected powerful machine learning pools and a sustainability aspect of modern datacenter. We可持续化数据中心作为一种管理多台服务器的排放方式。动态功率管理算法被提出用于减少电力消耗和二氧化碳排放。第8章展示了在忙模式和睡眠模式下的二氧化碳排放对比。

In this paper, we investigated the sustainable data center design for reducing power consumption and carbon dioxide emission. Dynamic power management algorithm is proposed sustainable data center as a way to manage three server pools and a sustainability aspect of modern datacenter. We presented the accuracy of selected powerful machine learning algorithms and the estimated power consumption and CO2 emission. Experimental results reveal that the core idea proposed sustainable data center design reduces power consumption and carbon dioxide emission significantly. Sleep mode can reduce SLA violation effectively. This research is ongoing research. Therefore, we focus dynamic power management for three server pool in this paper.

We have planned to present resource allocation algorithm and the effectiveness of proposed algorithm on data center by experimenting on java simulation program in the near future. And then we will evaluate effectiveness of proposed algorithm and to investigate the effectiveness of resource allocation policies on sustainability of data center.

REFERENCES