A State Of The Art Survey On DVFS Techniques In Cloud Computing Environment

Peyman Mokaripoor
Department of Computer Engineering, Sari Branch, Islamic Azad University, Sari, Iran
peymanmokaripoor@gmail.com

Mirsaeid Hosseini Shirvani
Department of Computer Engineering, Sari Branch, Islamic Azad University, Sari, Iran
Corresponding Author:
mirsaeid_hosseini@yahoo.com

***Abstract*—Distributed systems comprise miscellaneously heterogeneous computing resources such as high performance computing (HPC), grid computing and cloud computing in which these provision computing resources to their subscribers as a utility. Total cost of ownership (TCO) is the concept helping system owners to reconfigure their human and IT assets to reduce their costs rather that boosting their utilities tariff. Reduction of the vast volume electricity consumption as a big portion of operational expenditure (OPEX) in such large datacenters including hundred even thousands physical machines is first class concern both in economic and green goals viewpoint. Different methods have been done in literature to cope with power management such as virtual machine (VM) migration, server consolidation in virtualized datacenter environment, but aggressive VM migration and server consolidation executions deteriorate the situation in terms of power consumption and performance degradation. So, the dynamic voltage frequency scaling (DVFS) technique in infrastructure level can adjust server's operational voltage and frequency based on current workload to lower down power wastage and untimely server consolidation schemes. This paper presents a state of the art survey study on DVFS technique to lower down not only on processor chip but also on other peripherals such as cash memory and hard disks. Then it classifies the presented methods based on our thematic taxonomy and metrics derived from literature. It pave the way for other researchers to improve the current schemes.**

Keywords-- HPC, TCO, Cloud Computing, VM migration, Server Consolidation, DVFS

I. INTRODUCTION

Distributed systems comprise miscellaneously heterogeneous computing resources such as high performance computing (HPC), grid computing and cloud computing in which these provision computing resources to their subscribers as a utility [1]. As such, cloud computing is new paradigm that provisions cost efficient services to the users [2]. Its datacenter includes hundred even thousands of physical server so that it is severely energy hungry system [3]. Clouds are known with five essential characteristics such as on-demand, self-service, broad network access, resource pooling, rapid elasticity and measured service; three service model such as software, platform and infrastructure so-called SPI model; deployment models include private, public, community and hybrid [2,4]. Cloud is a good option for individuals and organizations without exact knowledge about their computing resource requirements such as startup companies. Also, cloud can provisions companies with their existing IT department in flash crowd situation by deploying hybrid model [5-6]. TCO concepts include capital expenditure (CAPEX) and OPEX. The former indicates infrastructure procurement costs whereas the latter indicates electricity bills, human salaries and etc. By applying TCO approach, the cloud providers can take over their costs. Cloud providers such as Amazon, Google, Salesforce and etc. are suffered from the vast volume of electricity consumption annually as their OPEX. For instance, Google spends 260 million Watt electricity per year [7]. Also, the big volume of power consumption produces large volume green gas emission too [8]. To this end, variety methods have been proposed in literature to manage power wastage such as VM migration, server consolidation techniques [3, 9-10]. Resources allocation in cloud environments needs smart scheduling techniques so that it meets both user's need and providers' need [8, 11-13]. Moreover, recently, DVFS techniques are pervasively being exploited to lower down power wastage in both infrastructure and operating system level [14-16]. Impetus of preparing the current survey study revolves around the fact that investigation in literature shows that there are not abundant research studies about DVFS in cloud computing environment. Firstly, we present our thematic taxonomy. Then we investigate and categorize researches based on our proposed scheme afterwards analyze them according to parameters derived from literature. The rest of the paper are organized as follows: section two briefly explains DVFS techniques. Our proposed thematic taxonomy is brought in section three. Section four and five respectively clarifies and compares detail of published papers in literature. Conclusion and future works are placed in section six.

II. Dynamic Voltage Frequency Scaling (DVFS)

The dynamic voltage frequency scaling (DVFS) technique can be applied to lower down the power consumption of the IT equipment. The DVFS enables servers and other peripherals to run at different combinations of frequencies with voltages to reduce the power consumption of the IT equipment. The energy consumption of a processor is approximately proportional to processor frequency and to the square of the processor voltage so that P α C.f.V^2 [14, 16]. Decreasing the processor voltage and frequency will cause the performance degradation. However, if the execution performance is not so important, scaling down will be exploited on the processor voltage and frequency to reduce the power consumption of the processor [15]. Moreover, DVFS and dynamic frequency scaling (DFS) can be applied to other peripherals such as RAM and cache memory whenever low bandwidth of them are in use [17-19].

III. Proposed Thematic Taxonomy on DVFS

Power management in datacenters is crucial both for saving economic viewpoint and environmental harm. For example, HPC located in Guangzhou China, Tianhe-2 is recently ranked as the fastest supercomputer in Top500 list [20] and Green500 [21]. Tianhe-2 includes 32,000 Xeon E5 and 48,000 Xeon Phi processor with totally 3,120,000 cores. It consumes huge amount of electricity. Consequently, it rises operational costs and emission vast amount of green gas. The DVFS technique is used in distributed system letting servers to work with appropriate pair of frequency and voltage based on current workload. It needs estimating workload behaviors to decide the optimal solution. The fig. 1 shows our thematic taxonomy of DVFS schemes including elements such as main reason, datacenter heterogeneity, controller, estimation technique and component. The DVFS mainly is used for two reasons at first to preclude power wastage in low workload volume and to suppress aggressive server consolidation. The element datacenter homogeneity indicates the research works are applied for what type of datacenter. DVFS techniques are controlled in both chip level and OS level the controller element is placed for this reason. As DVFS needs recognizing the workload behavior, the element estimation is based on profile-enabled and monitoring-enabled techniques. Moreover, DVFS is exploited for processor, RAM and cache memory components.

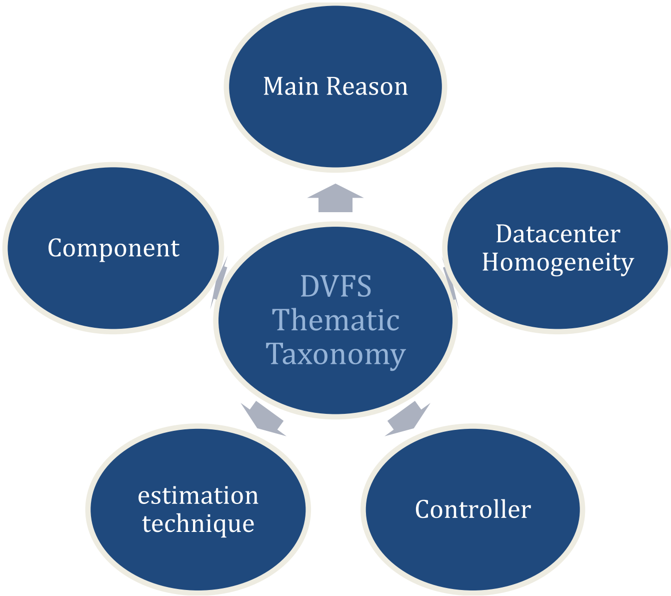

Fig. 1. Thematic Taxonomy on DVFS Schemes

IV. Review of DVFS Schemes in Literature

To cope with power wastage, a slack reclamation method is applied by rizvandi in [14]. It integrates task scheduler and DVFS adjustment to set appropriate linear combination of minimum and maximum frequency possibilities. The algorithm determines time information of tasks in compile time such as response time, deadline and upper limit of execution delay then based on derived information set DVFS parameters to save energy.

A smart resource allocation technique is used by leveraging both DVFS and VM migration method to set suitable running state and to preclude aggressive VM migration in [22]. The suggested scheme is used in heterogeneous IaaS environment. It determines exact resource demand instead of stating with percent metrics since in distributed and heterogeneous system percent concept are error prone.

The multiple optimization algorithm was applied in multi-core systems [19]. The algorithm takes into account both user SLA and system owners viewpoint in terms of response time and power consumption. It lowers down the the amount of frequency until the performance does not violate user SLA.

A MemScale algorithm was applied on memory system to recognize low bandwidth utilization for lowering down for the sake of power management in [17]. It applies DFS technique on memory channels to save energy. So, it benefits OS level controller to adjust memory subsystem frequency based on current requirement.

An algorithm has been proposed on memory system in distributed system to manage power wastage in [18]. The proposed Memory DVFS dynamically adjusts operational points based on current need. To this end, the controller algorithm sets memory sub systems into low frequency/voltage based on memory bandwidth utilization; then it assesses performance results and analyses power reduction model over real hardware. It reduces the frequency until preserving performance degradation threshold. On the other hand, the controller scales up the frequency if memory bandwidth utilization raising over threshold is observed. Overall, the scheme preserves trade-off between power consumption and performance.

An algorithm has been published to maximize resource utilization for power saving [24]. It applies VM migration in consolidation scheme to pack them over the minimum number of physical machines. It exploits DVFS technique to obstruct aggressive server consolidation execution as server consolidation is severely resource intensive in which it deteriorates the current situation. The DVFS technique take benefit of workload behavior derived by mining from profiling information. Then it adjusts operational frequency and voltage to cope with both performance guarantee and power saving problems.

V. Comparison of DVFS Schemes Based on Our Thematic Taxonomy

The DVFS is a promising technique to prevent power wastage in distributed large datacenters such as cloud environment. OEXP is a big portion of TCO includes human salaries, power consumption and maintenance cost. By applying DVFS on IaaS in cloud datacenter TCO will be significantly reduced. DVFS is applied not only on processor chip, but also it is applicable on RAM, Cash and Disk drivers. However, DVFS controlling can be done both in chip level and OS level. As such, mining techniques can be helpful in which the workload requirement would be profiled; then workload behavior in forthcoming instant will be detected. Based on detection as current workload, the combination pair of voltage and frequency will be adjusted provided it does not violate user SLA. Application of DVFS and DFS on memory system revolves around the fact that when memory bandwidth usage are very low it rises power consumption. If scaling down the memory system does not effect on application performance it will be exploited. Also, aggressive DVFS running may ruin the power-aware schemes because switching transition state between options incurs system overhead. DVFS-enabled cluster servers also can avoid aggressive server consolidation to manage power wastage. Table 1 shows classification of researches based on our thematic taxonomy.

Components	Estimation technique	Controller	Datacenter Homogeneity	Main Reason	Author(s)
Processor	Profiling	On-chip	Homo.	Green Goals	Ref.[14]
Processor	Monitoring	On-chip/OS-level	Hetero.	Green Goals/Consolidation	Ref.[22]
Cache memory	Profiling/ Monitoring	On-chip/OS-level	Homo.	Green Goals	Refl.[19]
Main Memory	Profiling/ Monitoring	On-chip/OS-level	N/A	Green Goals	Refl.[17]
Main Memory	Profiling	On-chip	Homo.	Green Goals	Ref.[18]
Processor	Profiling	On-chip	Hetero.	Green Goals/ Consolidation	Ref.[15]

Table1. DVFS Schemes Comparison Based On Our Subjective Taxonomy

VI. Conclusion and Future Direction

On the one hand, virtual machine migration and server consolidation are applied in virtualized cloud environment for cost reduction in terms of time and energy, but in some situation aggressive running the migration schemes deteriorate overall system performance since aforementioned processes are severely resource intensive. On the other hand DVFS is applied for power management and green computing goals. It will be exploited not only on processor chip, but also on other peripherals such as cache, RAM and disk drivers. Indeed, current researches show that all of them scale down voltage and frequency as operational device configuration based on their current requirement. The big challenge in DVFS and DFS leveraging is to predict exact requirement. The reason why the mining technique through profiling approach are crucial. However, profiling the most vital and effective parameters help precluding overhead and exact prediction. For instance, the time information of tasks such as execution time and deadlines, system information such as leakage and transition time to switch are very crucial. Also, the schemes related to DVFS and DFS must be aware of user SLA because frequency and voltage scaling down have drastic performance degradation. Consequently, leakage-aware, transition-awrae, QoS-aware schemes must be extended to manage power consumption and user QoS needs. Power management by leveraging DVFS and DFS are being applied in both CMOS level and OS level. Operating systems take benefit APIs to communicate with underneath hardware and issue the most appropriate command to take over power consumption; therefore aggressive DVFS and DFS may increase power consumption since transition switching is electricity intensive process. Moreover, the heterogeneity of underlying hardware should be taken into consideration because calculation of resource needed may be completely different in other machines. Future works can revolves around strengthening of appropriate estimation micro instruction for profiling along with ameliorating the prediction methods to detect execution deadline time and resource low bandwidth utilization point to decide the optimal adjustment.

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