DYNAMIC ENERGY MANAGEMENT IN CLOUD DATA CENTERS: A SURVEY

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ABSTRACT

Cloud data centers have become indispensable infrastructure for computing and data storage that facilitate the development of diversified services offered by the cloud. These data centers consume enormous amounts of electrical energy to process the cloud services resulting in large amount of CO_2 emissions, high operational cost, and affecting the lifetime of hardware equipments. This necessitates the development of efficient energy management techniques in cloud data centers for both economic and environmental standpoints. Energy management at data centers can be static or dynamic. Energy consumption can be reduced by employing dynamic energy management techniques both in hardware and software levels at cloud data centers. This paper surveys various issues related to dynamic energy management in cloud data centers.

KEYWORDS

Cloud Data Center, Virtualization, Dynamic Energy Management, & Server Consolidation

1. INTRODUCTION

Data Centers have emerged as a back-bone infrastructure, housing large number of IT equipments such as servers, data storage, network devices, power and cooling devices etc. that facilitate the development of wide variety of services offered by the cloud [1] Currently, several service providers such as Amazon, Google, Yahoo, Microsoft, IBM and Sun, have their own data centers to provide the scalable services to a large customer base [2-3].With the rapid development of IT industry and increasing demand for cloud services, the number of data centers have increased. These data centers consume enormous amount of energy to process its services resulting in increased energy consumption. The surging energy consumption of these data centers has become a serious concern from both economic and environmental standpoints.

According to McKinsey report [4], the energy consumption of data centers is $11.5 billion in 2010 and it doubles every five years. Gartner [5] also estimated that world wide IT infrastructures are responsible for 2% of global CO_2 emissions and energy related costs account for the 12% of the total economical expenditures. The excessive energy consumption at data centers leads to high operational cost, large amount of CO_2 emission and falling lifetime of hardware equipments.

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Hence, it is necessary to design energy-efficient data centers not only for ensuring system reliability but also reducing environmental impact and operational cost.

Energy management techniques at the data centers can be static or dynamic. The static energy management techniques fail to address the run time adaptation of data centers in response to workload changes. The dynamic energy management techniques configure the data center at both hardware and software levels dynamically based on workload variability.

Further, the energy conservation can be achieved by efficient utilization of data center resources. Virtualization technology is one such powerful technology to address this energy inefficiency by increasing resource utilization [6].This technology allows multiple virtual machines (VMs) to share the resources on a single physical machine (PM). The features such as VM isolation and VM migration along with dynamic resource provisioning can be used either to consolidate virtual machines on fewer physical servers or to balance the load across physical servers in data centers, thereby ensuring applications' performance. This paper surveys the various techniques and issues related to dynamic energy management in cloud data centers.

The rest of this paper is organized as follows. Section 2 explains taxonomy of energy management mechanisms in virtualized data centers; section 3 presents an overview of dynamic energy management techniques in cloud data centers and finally, section 4 presents the conclusion.

2. TAXONOMY OF ENERGY MANAGEMENT TECHNIQUES IN CLOUD DATA CENTERS

It is necessary to understand the background terminologies involved in the context of energy management techniques. The energy consumption (E) at cloud data center is defined as a total amount of power (P) consumed over a period of time (T) while performing the work [7], i.e.,

$$E = P * T \qquad (1)$$

Thus, the energy conservation at the cloud data centers can be achieved by controlling average power consumption (P) over the period of time. As per taxonomy [7], the energy management approaches in cloud data center can be classified into static and dynamic energy management techniques as shown in Fig.1.

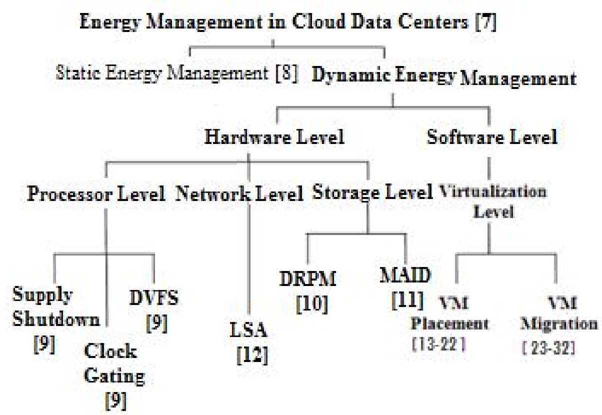

Fig .1. Taxonomy of Energy Management Techniques in Cloud Data Centers

Static Energy Management (SEM) technique [8] uses low-power hardware components at the data centers for energy savings. The request for the cloud services running in the data center is volatile in nature. This technique fails to address the runtime adaptation of data centers in response to the service demand to avoid resource wastage and it is also a very expensive technique for energy conservation.

3. OVERVIEW OF DYNAMIC ENERGY MANAGEMENT TECHNIQUES

Dynamic energy management (DEM) techniques dynamically reconfigure the system based on current resource requirements of the requested services. It utilizes the power scalable hardware components and software approaches to optimize the energy consumption at data centers.DEM techniques are classified into hardware and virtualization assisted techniques based on the level of their applicability.

3.1. Hardware Level Energy Management Techniques

The energy management techniques need to be applied on each hardware components such as the processors, network equipments, and storage devices to reduce overall hardware level energy consumption at cloud data centers.

3.1.1. Processor Level

Energy consumption of a processor consists of two components such as static power and dynamic power depends on the usage of various resources at server [7]. The dynamic power consumption of a CMOS-based processor is given by

$$\text{Dynamic Power} = A * F * C * V^2 \qquad (2)$$

Where A is the percentage of active gates, F is clock frequency of the processor, C is capacitance load of the processor, and V is the voltage supplied. The techniques such as Dynamic Voltage and Frequency Scaling (DVFS), Network Level Clock Gating and Supply Shutdown are used for power management in processor level.

3.1.2. Network Level

As the size of the data center and network infrastructure is exploding, it is necessary to address the energy consumed by the network devices such as routers, switches, NIC, etc. Switches form the basis of interconnection fabric that delivers job requests to the computing servers for execution. The energy consumption of a switch depends on the type of switch, number of ports, port transmission rates and employed caching solutions. The energy consumed by a switch can be generated by the following equation;-

$$P_{\text{Switch}} = P_{\text{Chassis}} + N_{\text{Line cards}} * P_{\text{Line card}} + \sum_{i=0}^{R} N_{\text{Ports}} * P_r \qquad (3)$$

Where P_{Chassis} is the power consumed by the switch base hardware, $P_{\text{Line card}}$ is the power consumed by the active line card and P_r is the power consumed by the active ports. The techniques such as Link State Adaptation (LSA), Idle Elements Shutdown are used for power savings in network level.

3.1.3. Storage Level

The storage devices constitute a significant fraction of the overall energy budget. The storage level energy management techniques [38] can be divided as follows:-

- **Hardware based techniques** increase the disk power conservation by maintaining storage hierarchy to strike the right balance between performance and power consumed by storage resources
- **Disk management techniques** introduce the new disk management layer on top of the file system, which controls disk configuration and data layout to achieve power optimal disk access patterns
- **Caching techniques** reduce the power consumption at storage level by allowing large fractions of the storage system to remain idle for longer periods of time and switch to lower power modes

3.1.4. Summary of Hardware Level Energy Management Techniques

System Resources Considered	References	Techniques used	Description
Processor Level	Benini et al [9], Beloglazov et al[7]	Dynamic Voltage and Frequency Scaling (DVFS)	In DVFS, the voltage and frequency of the processor can be scaled dynamically depending on the request that is being processed.
	Benini et al [9]	Network Clock Level Gating	In Network Level Clock Gating, the supplied voltage or the clock frequency is reduced for idle components.
	Benini et al [9]	Supply Shutdown	In Supply Shutdown, the idle components are powered off to decrease power dissipation as there is a leakage of current even if all the clocks are halted.
Network Level	Nordmen et al[12],	Link State Adaptation (LSA)	In LSA, the link speed of network can be changed dynamically to reduce energy consumption in networks.
	M. Gupta et al [35]	Switch Shutdown	In Switch Shutdown, the Ethernet switches are shutdown dynamically based on the traffic arrivals, buffer capacity and bounded maximum packet delay for energy conservation.
	Heller et al [36]	LSA + Idle elements shutdown	This hybrid approach uses both LSA and Switch shutdown methods to conserve energy on network level.
Storage Level	Gurumathi et al [10]	Dynamic Rotations Per-Minute(DRPM)	In DRPM, the speed of disk rotation can be changed dynamically per minute (RPM) for controlling the power explored in the spindle motor driving the platters.
	Colarelli et al [11]	Massive Array of Idle Disks (MAID)	In MAID, only those disk drives in active use are spinning at any given time. MAID reduces power consumption and prolongs the lives of the drives.
	Bianchini et al[37]	Popular Data Concentration (PDC)	This method selects the most popular files based on frequency of disk access and least popular disks are shutdown for energy conservation.

Table.1. Summary of Hardware Level Energy Management Techniques

For efficient energy conservation, the hardware energy management techniques should consider all resources such as Processor, Network and Storage etc. The above mentioned hardware techniques are applicable at individual server level for energy conservation. Hence, these hardware level energy management techniques do not contribute much in total energy conservation at cloud data centers. The energy consumption can be further reduced by applying energy management techniques at software (virtualization level) at cloud data centers.

3.2. Virtualization Level Energy Management Techniques

The energy consumption problem has been addressed partially by making improvements in the physical infrastructure of modern data centers. According to Open Compute project report [33], 93% of the data center's energy consumption depends upon efficient utilization of computing resources at data centers. Virtualization is a key technology that facilitates the better use of available data center resources using the technique called server consolidation [13]. This technique involves consolidating multiple physical server workloads into single physical server to increase the resource utilization. Thus, it allows for reduction in the total number of physical server used, minimizes the server sprawl as well as total data center space requirements. The server consolidation can be performed either statistically or dynamically.

- In **static consolidation**, VMS are placed on physical servers for a long time period and not migrated even if workload changes.
- In **dynamic consolidation**, VMs are placed on physical servers at runtime and migrations of VMs performed automatically in response to the current workload demands. This helps in utilizing the data centers resources efficiently.

The steps for server consolidation (Fig.2.) are as follows:

- Determining the capacities of VM (VM sizing) for running applications and placing of VMs on PM based on their requirements
- Monitoring and profiling the resource utilization for hotspot detection (overloaded and under loaded PMs)
- Resize and remap the VM to another PM.

The VM placement and VM migration act as backbone to VM consolidation process. The challenges for efficient VM consolidation are:-

- Finding the proper VM- to-PM mappings to minimize the acceptable cost function
- Dynamic hotspot detection
- Performing VM migration process with minimal service downtime and resource consumption during migration process

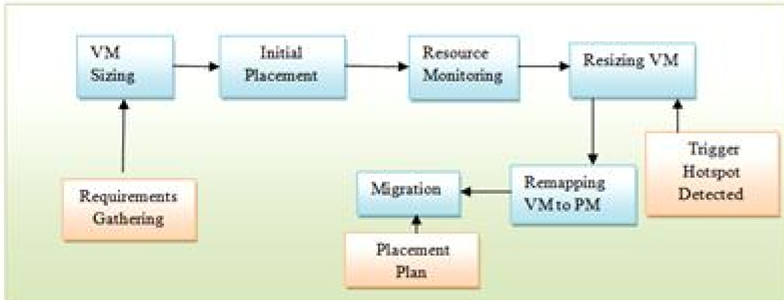

Fig.2. Server Consolidation Steps

3.2.1. Virtual Machine Placement

VM placement [14] is the process of mapping VMs to PMs. The placement approach should consider multiple resources such as CPU, memory, disk storages and network bandwidth to reduce the energy consumption at data centers and also needs to maintain the energy performance tradeoff.

The VM placement involves two main steps:

- Provisioning of resources for the virtual machines according to the capacity requirements of corresponding applications (VM sizing)
- Actual placement of VMs onto PMs.

VM placement problem is a NP –Hard problem [34] and no optimal solution exists for it. A set of heuristics is used to solve VM placement problem.

3.2.1.1. State- of-the Art in VM Placement

The energy conservation at data centers increases by maintaining optimal placement of the VMs on the PM. The existing VM placement heuristics are classified into the following:-

- **Availability aware VM placement -** The main challenge of the VM placement algorithms is to identify suitable VM-PM mapping so as to satisfy workload demands of various applications. Once the hotspot is detected in source PM, the VM placement algorithm finds the workload demands of each VM and identifies the target PM based on the resources availability such as CPU, memory, network and disk [13-17].

- **Affinity aware VM placement** can be achieved by considering both availability of VM's resources and relationship among VMs. This approach improves the response time of the applications and optimizes the usage of resources. If a hotspot has occurred because of network resource crunch among PMs, then placing two communicating VMs on the same PM will reduce the network overload. In [15] [20], the intra and inter-PM network traffic and also network topology has been considered for VM placement. In [17] [19], the inter memory sharing VMs are identified and placed on a single PM. This reduces the number of servers and memory resource used.

- **Workload aware VM placement-** The efficient VM consolidation can be accomplished by considering workload interference between co-located VMs to avoid performance degradation. In workload aware VM placement mechanism, the different combination of workload mix such as CPU, I/O intensive, etc., are investigated in order to find optimal VM placement. The benefits of workload mixing can be proactively predicted by using machine learning algorithms which can be used for VM placement decisions [21] [22].

3.2.1.2. Analysis

The VM placement algorithms are analyzed based on the following parameters:-

- **Resources availability:** the availability of resources (CPU, memory, network and disk of PM determines the number of VMs on it.
- **Heterogeneity** of PMs
- **Workload type** of VMs

An efficient VM placement algorithm should consider all the above mentioned parameters during VM placement, but most of the existing VM placement algorithms have not considered the all parameters.

3.2.2. Virtual Machine Migration

VM migration [23] has become an indispensable tool that facilitates resource management at cloud data centers for a wide variety of key scenarios such as load balancing, fault- tolerance, hot spot mitigation and server consolidation. The VM migration can be either offline or live. The offline VM migration follows traditional suspend and resume mechanism which increases service down time, causes performance degradation of applications running in VM. Live migration relocates the VM from source to target PM without disturbing the applications running in the VM resulting in minimal downtime. In live migration process, the virtual disks are stored on some shared storage such as Network File Systems, which is accessible from entire network. Hence, virtual disks are not transferred. The steps of Live migration are as follows (Fig. 3):-

1. Once migration process is triggered, source PM transfers the VM’s memory pages to target PM without suspending the VM (and hence it is called live migration). The dirtied memory pages during the migration process are transferred to target PM which leads to multiple iterations. This is known as **iterative precopy-phase**.
2. This iterative process ends and enters into suspend -and- copy phase when either one of the following conditions occurs:
   a. The number of pre-copy iterations are greater than the fixed threshold value (n)
   b. The network traffic generated is greater than the multiples of VM size
   c. The memory page dirty rate is greater than a memory transmission rate
   d. The number of memory pages dirtied during current iteration becomes smaller than a predefined threshold

3. In suspend-and-copy phase, the VM being migrated is suspended in the source PM and the remaining dirty memory pages as well as the state of the CPU register are transferred to the target PM. Once the migration process is completed, the target PM resumes the VM.

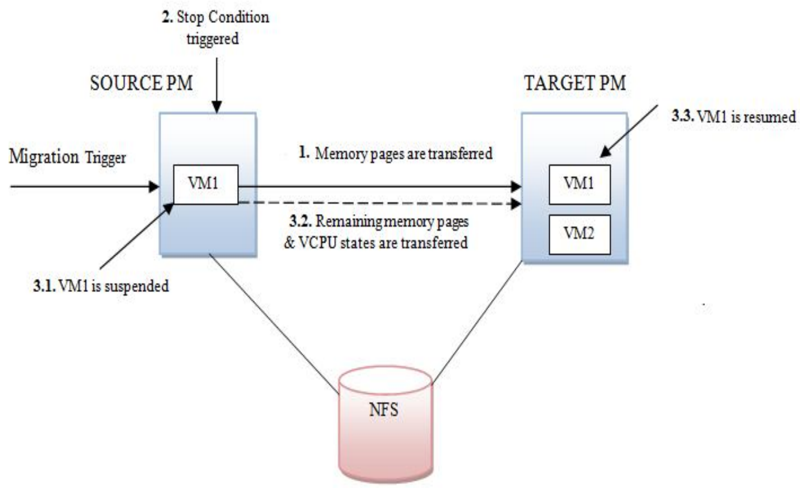

Fig. 3. Live Virtual Machine Migration Mechanism

3.2.2.1. State-of- the Art in Live Migration Research

It is hard to provide a quick live VM migration with less resource overhead because large amount of data transfer during migration results in performance degradation of VM applications. The response time and throughput of the data center applications heavily depends on the VM migration process. Hence, it is essential to improve the performance of migration process to facilitate efficient resource management at data centers.

3.2.2.1.1. Optimizations of Live Migration

Many methods have been proposed to improve live migration and optimize its performance metrics such as total migration time and downtime to provide uninterruptible services to applications running in VMs.

- **Memory compression:** Live migration performance is improved by minimizing the amount of data transfer to the destination using the technique called memory page compression [24]. This technique compresses the source PM memory pages to minimize the amount of data during live migration process and decompresses the memory pages in target PM. However, the performance of application running in VM depends on selection of suitable compression and decompression algorithms, resources availability and workload characteristics. The changes in workload characteristics introduce significant resource overhead during compression and decompression process leads to performance degradation of applications running in VM. Therefore, it is necessary to ensure trade-off between resource overhead and compression effects to achieve efficient migration.

- **Delta page transfer:** This technique reduces the network bandwidth consumption by maintaining a cache of previously transferred memory pages. This optimizes the transmission of dirtied pages by sending the difference between cached page content and page content that is going to be transferred. This improves the live migration process with reduced risk of service interruption [25][32].
- **Data deduplication**: This technique finds identical data inside the memory and disk of a single VM and removes that duplicates during the live migration process. The performance of this technique depends on selection of suitable techniques for finding identical data on memory and disk contents [31-32].
- **Post-Copy Approach:** This approach postpones the memory page transfer phase until after the VM's CPU state has been transferred to the target PM and resumed there. The performance of post-copy approach depends on the way and which the memory pages are fetched from source PM during live migration process. There are three main ways the memory pages are fetched from source PM [26].

    - **Post-copy via demand paging-** The page faults are serviced by requesting the referenced page over the network from the source node
    - **Post-copy via active pushing-** This technique, proactively pushes the memory pages from source to the target, while VM continues executing at the target PM
    - **Post-copy via prepaging-** This approach extends the active pushing technique by estimating the spatial locality of the VM's memory access pattern in order to anticipate the occurrence of major page faults

  The post-copy approach ensures that each memory page is transferred at most once, hence avoiding the duplicate transmission overhead of pre-copy approach. However, this approach does not have the reliability as Pre-Copy approach because VM cannot restart in the source PM, if the destination PM crashes.
- **Hybrid pre and post copy**: This hybrid approach performs single round of pre-copying which precedes the virtual CPU state transfer. This is followed by post-copying of the remaining dirty pages from the source PM. Therefore, it gets the benefits of both approaches and improves live migration process [27].

3.2.2.1.2. Multiple VM Migrations

Whenever there is a need to shift entire virtual clusters to different locations, it requires large amount of data to be transferred over the network which results in network and CPU overhead. This leads to performance degradation of applications running in the PM. Hence, the identical contents of co-located VMs in the physical machine can be pro-actively tracked and transferred only once to the target PM. This improves the performance of multiple VM migration. This is known as "Gang Scheduling" of virtual machines [27-32]. It optimizes both memory and network overhead of migration.

3.2.2.1.3. Migration in Network

Several enterprises have data centers that are spread across the world to offer efficient services to worldwide users. The network can be LAN or WAN. Live migration of VMs across worldwide data centers entails transferring virtual CPU, memory state and disk state to target PM and also it necessitates network re-configuration as the VM shifts into a new subnet where a new IP address is assigned to the VM [29-30] [32].

3.2.2.2. Analysis

The live migration process consumes resources such as CPU and network which can seriously impact the performance of both the VM being migrated as well as other VMs in the PM. The performance of the migration approach depends on the parameters such as

- **VM size** consumes significant amount of CPU and network resources during live migration process. Thus, an optimal VM size needs to be selected to reduce resource overhead during migration process.
- **Page dirty rate** indicates the rate at which memory pages are dirtied in source PM during migration process. If page dirty rate increases, it results in more data being sent per iteration over the network, results in increasing of total migration time
- **Available network capacity** between source and target PM
- **Available CPU resource** at both source and target PM

The following performance metrics should be considered to evaluate performance of live migration process;-

- **Migration time-** the time between initiation of migration and successful completion
- **Service downtime –** the time for which service is unavailable during migration
- **CPU and network resource consumption** during migration process

Reference	Techniques used	Parameters considered				Performance metrics accounted			Single VM/ Multiple VM	WAN		
		VM size	Page dirty rate	N/W traffic	CPU cycles	Total mig, down time	N/W BW	CPU util		Y/N	n / w	storage
clark et al [23]	Pre copy		✓	✓		✓			Single VM	No		
Jin et al [24]	Precopy +memory compression		✓			✓			Single VM	No		
Hacking et al [25]	Pre copy+ delta page transfer		✓	✓		✓	✓		Multiple VM	Yes		✓
Hines et al [26]	Post copy+ adaptive prepaging +dynamic self ballooning		✓			✓			Single VM	No		
Sahni et al [27]	Precopy+post copy		✓			✓			Single VM	No		
Deshpande et al [28]	Precopy+multiple migrations		✓	✓		✓	✓		Multiple VM	No		
Riteau et al [29]	Precopy+content bashed hashing		✓			✓			Multiple VM	yes		✓
Bradford et al [30]	Write throttling + DNS and IP tunneling		✓	✓		✓	✓		Multiple VM	yes	✓	✓
Wood et al [32]	Delta page transfer+ data deduplication+ VPN configuration		✓	✓		✓	✓		Multiple VM	yes	✓	✓
Zhang et al [31]	Precopy+ data duplication		✓			✓			Single VM	No		

Table .2. Comparison of state-of-art existing live migration approaches

From Table 2, it is observed that the two important parameters such as VM size and available CPU cycles, have not been taken into consideration during migration process. For efficient migration, all the mentioned parameters should be taken into account and also the performance of the migration algorithm needs to be measured.

4. CONCLUSION

The cloud data centers are prominent hosting infrastructure for provisioning of its services. The surging energy consumption of these data centers has become a critical problem from both the economic and environmental standpoints. This paper presents an overview about various dynamic energy management techniques both in hardware and virtualization levels and highlights issues and its significance. However, the hybrid approach that covers both hardware and resource management levels (virtualization) needs to be developed to provide continuous and efficient energy management in virtualized data centers.

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