Open Access Journal

Journal of Power Technologies 94 (2) (2014) 1–10

journal homepage:papers.itc.pw.edu.pl

Implementation of Server virtualization to Build Energy Efficient Data Centers

Mueen Uddin*[,a], Asadullah Shah[a], Adamu Abubakar[a], Imran Adeleke[b]

[a]*Kulliah of Information Communication Technology*
International Islamic University Malaysia, Malaysia
[b]*Department of Computer Science*
Adeniran Ogunsanya College of Education, Lagos, Nigeria

Abstract

The rapid growth in the size and capacity of data centers driven by a continual rise in the number of servers and other IT equipment is causing an exponential increase in the demand for power. All data centers are plagued by the operational presence of thousands of servers as major components. These servers consume a huge amount of power while performing little in terms of useful work. In an average server environment, 30% of servers are "zombies"—they merely consume power while having a utilization ratio of only 5 to 10%. Server virtualization contributes to this problem by offering an opportunity to consolidate multiple underutilized volume servers into a single physical server, thereby reducing the physical and environmental footprint of data centers. This paper suggests implementing "server virtualization" to achieve energy efficient data centers. The proposed technique increases the utilization ratio of underutilized servers up to 50%, saving a huge amount of power and at the same time reducing the emission of greenhouse gases.

Keywords: Server Virtualization, Consolidation, Energy efficiency, Energy efficient data centers, Server Categorization

1. Introduction

Most organizations today are faced with conflicting goals and challenges. They have geographically distributed workforces, with headquarters, data centers, branch offices, and mobile workers scattered widely. Everyone needs to access email, file shares, and mission critical applications, and the speed of access directly ties into employee productivity. So computing resources have been widely deployed in many locations to give local workers the best possible service delivery. However, this approach is now seen as wasteful and expensive, with extra hardware and software to buy and maintain for many locations, and often few local IT staff to support the systems. As budgets get tighter, organizations are looking for solutions to handle this burden. IT consolidation is the number one approach today, taking infrastructure out of remote offices and into the main data center as a way to cut costs and boost IT staff productivity.

As corporations look to become more energy efficient, they are examining their operations more closely. Data centers are a major consumer of energy in their overall operations. In order to handle the sheer magnitude of today's data, data centers have to use much more power and servers have become larger, denser, hotter, and significantly more

*Corresponding author
Email address: mueenmalik9516@gmail.com (Mueen Uddin*,)

costly to operate. One of the areas of IT businesses where environmental sustainability is becoming important is data centers [1]. They are found in nearly every sector of the economy, ranging from financial services, media, high-tech, universities, government institutions, and many others, use and operate data centers to aid business processes, information management and communication functions [2].

Today's data centers are big power consumers and they are filled with high-density, power hungry IT equipment. Gartner warned that- if data center managers remain unaware of energy problems, they would most probably run the risk of doubling their energy costs between 2005 and 2011 [3]. If we assume that data center energy costs continue to double every five years, they will substantially increase by 1,600% between 2005 and 2025 [3]. Data centers contain tens of thousands of servers; plans are ready for installing millions of servers to cope up with ever increasing user demands [4]. An EPA Report to Congress on Server and Data Center Energy Efficiency completed in 2007 estimates that US data centers consume 1.5% of total US electricity consumption for a cost of $4.5 billion [5]. During the period 2000 to 2006, data center electricity consumption doubled in the US and was set to double again by 2011 to more than 100 billion kWh. This is equal to $7.4 billion in annual electricity costs [6].

Organizational computational demands have driven the mandate for large data centers, the massive server farms to run today's Internet, financial, commercial and business applications to aid business progression, information management and communication purposes [7]. High performance computing data centers are rapidly increasing in both size and magnitude, due to wide acceptance of hosting and performing extensive services and applications by large scale heterogeneous, multi-tier server clusters called blades and resource management in numerous businesses, Internet and e-commerce applications. Thousands of servers are densely packed in machine rooms to provide services to scamper businesses efficiently and cost effectively [8]. The increased load on these facilities is pushing the demand for installing millions of servers to match ever-increasing business needs [9]. All data centers are predominantly occupied by low cost underutilized volume servers also called x-86 servers as major components for performing different processes and services for end users [10]. With the recent development and growth in data centers, their number continuously increases as the demand for storage, speed, backups and recovery and computation increases. These servers consume a huge amount of power and generate too much CO_2, without being properly utilized to perform valuable work. In an average server environment, 30% of the servers are "dead" only consuming energy, without being properly utilized. Their utilization ratio is only 5 to 10% [11]. This results in issues like huge power consumption by data centers, which ultimately results in emissions of greenhouse gases. Research is going on to create techniques and opportunities to make these servers more useful and energy efficient. As new servers are being added continuously into data centers without considering the proper utilization of already installed servers, it is causing an unwanted and unavoidable increase in energy consumption, as well as an increase in physical infrastructures.

The latest emerging technology called virtualization is used to achieve energy efficient data centers by providing a solution called server consolidation to overcome some of the IT inefficiencies. Server Consolidation increases the utilization ratio of various servers by 50% or even more, saving a huge amount of energy. Thus, it helps in implementing green data centers to ensure that IT infrastructure contributes as little as possible to the emission of greenhouse gases, and helps to regain power and cooling capacity, recapture resilience and dramatically reduce energy costs and total cost of ownership [12].

To overcome some of the problems highlighted above, this paper focuses on the utilization of underutilized servers. The proposed technique categorizes the available servers into three resource pools depending on their workload and usage. After categorizing, server consolidation is applied on all categories depending on their utilization ratio in the data center. This process reduces the number of servers by consolidating the load of multiple servers on one server.

2. Problem Background

We are living in a global world where matters such as shortage of energy, global warming and effects of greenhouse gases have made environmental care a priority both for government and business organizations, and society as a whole. Information Technology (IT) cannot remain alien to this challenge, and all agents involved in their development, implantation or utilization have started to consider all possible efforts to mitigate the impact of IT on the environment. Today, energy consumption is a critical question for IT organizations, either to reduce costs or to preserve the environment. Business firms are investigating their operations more intimately to become energy efficient, green and environment friendly [13].

Data centers are indispensable components of businesses' infrastructure supporting the Internet, digital commerce and the electronic communication sector. Their major role is to provide guaranteed reliable power, security, cooling and connectivity to the rest of the Internet via a high capacity backbone network. Other benefits include—traditional business oriented goals such as support for business operations around the clock (resilience), lowering the total cost of operation and the maintenance needed to sustain business functions (total cost of ownership), and the rapid deployment of applications and consolidation of computing resources (flexibility) [14]. Data center power utilization can be categorized into different metrics of power usage, which can be defined as:

Rack power utilization: The power utilization ratio is highest at rack level because a rack consists of energy intensive computer equipments called servers and they use the maximum load per square foot of floor space within a data center.

Simple computer room power utilization: The power utilization ratio is lower than rack power density because the energy required by the racks is spread out over the entire raised floor space, while energy is utilized by single computing room.

Total computer room power utilization: It's higher than simple computer room power density because it includes the power requirements of all equipment that supports the operation of the data center.

Building power utilization: The power density is lowest at building level because it includes floor space that is much less energy intensive than computer and support electronic rooms.

Data centers are requiring more power to handle the extent of user data and to provide output promptly. Data center IT equipment consists of many individual devices like storage devices, servers, chillers, generators, cooling towers and many more. Servers are the main components responsible for performing almost all the processing being done in data centers. Servers also consume a lot of power as they are so numerous and their size continuously increases with the increase in size of data centers [15]. According to IDC, the cost to power the servers will exceed the cost of servers by next year. Data centers are one of the largest energy consumers, accounting for approximately 2% of total global energy use [16]. As the demand for power continues to increase, data centers are faced with several power, cooling, performance, and space constraints associated with environmental, technological, and economic sustainability. Improving the energy efficiency and environmental performance of data centers is therefore at the forefront of organizations' actions in 'greening' their information technology [16]. The data center industry along with other organizations like Green Grid, Energy Star, EPA, VMware, IBM, Microsoft and Oracle are trying their level best to propose new solutions to counter power and underutilization issues [17]. Research is being carried out at different forums to resolve power problems, especially in developing countries like Pakistan. It focuses on the data center industry in Pakistan especially tier level data centers - to provide data center managers and operators with new techniques to counter power problems by shifting to a new paradigm of green computing.

The continuous increase in power consumption by servers and data centers has shifted the focus of power management techniques to the data center industry. Energy efficiency in data centers is achieved by optimizing computing resource usage, by using the smallest computing resources—and power—to process maximum number of valuable tasks [18]. Efficient resource management is a key concern for data center operators seeking to meet application service level agreements and reduce power and operational costs [19]. The data center industry is now realizing the importance of reducing both energy and power consumption by pointing out negative environmental effects, high operating costs, power density problems, and expensive infrastructure requirements [20].

3. Energy Efficiency in Data Centers

Energy is used for accomplishing a particular task, e.g., moving a car, lighting a room, or even performing a computation. It can take many forms such as electrical, light, mechanical, nuclear, and so on, and can be converted from one form to another. For computing systems and data centers, energy is delivered as electricity. Power is the instantaneous rate of energy use, or equivalently, energy used for a task is the product of average power used and the time taken for the task [21].

$$Energy = AvgPower \times Time \qquad (1)$$

The typical units for energy and power are Joules and Watts, respectively, and 1 Joule = 1 Watt×1 second. For computer systems, energy efficiency is defined as the ratio of "computing work" done per unit energy. This metric varies from application to application since the concept of work done differs. For example, it might be transactions/Joule for Online Transaction Processing (OLTP) systems, and searches/Joule for a search engine. Energy efficiency is also equivalent to the ratio of performance, measured as the rate of work done to power used. For a fixed amount of work, maximizing energy efficiency is same as minimizing energy [22]. Thus, unlike performance optimization, energy efficiency can be improved by reducing power, time, or both. The most common definition of power efficiency is the ratio of output power to input power [23]. Power supply designers are being asked to improve efficiency as high as technology will permit. Energy efficiency impacts end users in terms of resource usage costs, which are typically determined by the Total Cost of Ownership (TCO) incurred by a resource provider. Higher power consumption results not only in increased electricity bills, but also in additional requirements for a cooling system and power delivery infrastructure, i.e. Uninterruptible Power Supplies (UPS) and Power Distribution Units (PDU). In the last few years power efficiency has become a top priority instead of the cost. The challenge for the power industry is to achieve 90% overall efficiency, which is possible within the bounds of cost and the technology available today [22].

Energy efficiency is achieved by using technologies that require less power to perform the same task. A compact fluorescent light bulb that uses less energy than an incandescent bulb to produce the same amount of light is an example of energy efficiency. We are in a society where fuel shortages, global warming, power shortages and reductions of carbon footprint are becoming pressing issues. It is important that all appliances, equipments and other heavy usage machinery operate as efficiently as possible. It is for this reason that power technology is becoming an important field of specialization, as most heavy machinery operates on AC or DC electrical power. Energy efficiency in computing has historically improved much more slowly than performance or cost [24]. Power demands required by the data center industry are met by considering the following factors:

- Power is available to the data center facility, but power distribution infrastructure is constrained.
- Power is available to the facility, but standby or backup power is insufficient for growth.
- Power is available in the general area, but utility constraints prevent delivery to the data center.
- Power costs are excessive in the region in which the IT equipment and facilities are located.

4. Problem Statement

Data centers are plagued with thousands of servers performing processing for end users to facilitate and accomplish large business goals. As businesses are growing rapidly, especially e-businesses, the need for large and complex data centers is evident. The problem with most of the data centers is that almost 90% of the servers remain idle most of the time, performing nothing but consuming huge energy and power which generates an enormous amount of CO_2.

5. Proposed Solution

The energy efficient data center is gathering momentum as organizations started realizing its importance in energy conservation and sustainable development. New policies and technologies should be implemented in cutting down energy costs and savings. An energy efficient data center should be designed; keeping in view many design parameters, creating an eco foundation, and leading to a lower total cost of ownership (TCO). These parameters range from data center physical layout and design, cooling system, cabling, and power system, IT infrastructure including servers and storage and IT design parameters like consolidation and virtualization for most energy efficient and optimal utilization [8]. This paper proposes a new technique for data center managers to combine the workload of multiple servers onto fewer servers and then properly utilize their efficiencies, i.e., hardware and software efficiencies. The proposed technique uses server consolidation; types of virtualization to achieve energy efficiency in data centers and at the same time reduce the emission of greenhouse gases, making data centers energy efficient and green. The proposed technique helps to ensure that IT infrastructure contributes as little as possible to the emission of greenhouse gases, and helps to regain power and cooling capacity, recapture resilience and dramatically reduce energy costs and total cost of ownership.

5.1. Server Virtualization

Virtualization has become popular in data centers since it provides an easy way to partition physical resources, allowing multiple applications to run in isolation on a single machine. The creation and management of virtual machines is called virtualization [25]. It decouples software from hardware and splits multi processor servers into more independent virtual hosts for better utilization of hardware resources, allowing services to be distributed one per processor. It promises to dramatically change how data centers operate by breaking the bond between physical servers and the resource shares granted to customers [26]. It helps to consolidate the load of multiple underutilized volume servers onto fewer servers, thereby reducing costs, energy consumption and cooling requirements. Enterprise Management Association research shows that over 90% of all enterprises are very keen to implement virtualization, and the market is growing at over 20% p.a. Virtualization can be applied to operating systems, desktops, applications, storage, and networks, depending on the end user and business requirements. There are many vendors providing virtualization like VMware, Cisco, Citrix, EMC, Hewlett-Packard, IBM, Microsoft, NetApp, Novell, Oracle, Quest, Sun, Symantec, Virtual Iron, and many more [27]. Some of the major benefits of virtualization technology are:

- Easier, faster disaster recovery/business continuity planning.
- Fast, agile, and responsive self-service provisioning.
- Effective management of IT services to meet business needs.
- Rapid scale-up (and scale-down) of compute resources to satisfy user load .
- Faster, cheaper test and development for inhouse applications.
- Simple, responsive, utility-style ‘cloud computing’ infrastructure.
- Hardware and Software Maximization. Workload configuration and utilization.
- Performance and Energy measurement techniques. CO_2 emission reductions.
- Saving total cost of ownership.
- It reduces the total amount of hardware used in your environment.
- Idle Virtual servers can be powered off.
- The total volume of space, air, and rent will be reduced and, data centers can be utilized up to 100 times more.

5.2. Proposed Technique (Server Consolidation)

Data center managers and top management are realizing that proliferating power demands are the main reason for enormous increase in all types of costs in data centers. This is evidently seen in Google server farms and other enterprises like IBM, Dell, Amazon and e-Bay in recent years [28]. An estimate placed the total size of server farms in 2004 at 63,270 server machines and this trend of server enlargement is increasing very rapidly, creating problems for enterprises to cope with energy demands and power requirements.

Ironically, several studies have shown that a typical server in a data center is seriously underutilized; average server utilization varies between 11 to 50% for workloads from sports, e-commerce, financial and Internet proxy clusters [29]. As new servers are being added continuously without considering the proper utilization of already installed servers, it's causing an unwanted and unavoidable increase in energy consumption, as well as an increase in physical infrastructure like over sizing of heating and cooling equipment [13].

Organizations are rapidly evaluating and implementing virtualization as they look to further consolidate and reduce the hardware footprint in their IT environment [30]. Server virtualization is a trend that is sweeping the data center industry. It is a technology that data center operators can use to reap tremendous financial and capital expenditure savings. Servers may sit idle for a large percentage of the time, all the while consuming power but performing no useful tasks. Every watt of power expended on an idle server is also a watt of power that is turned into waste heat that must be removed from the data center. Thus, power consumption by idle equipment has a two-fold cost penalty.

- Power is expended on equipment that is not performing a useful function.
- Power is expended on removing the waste heat produced by the idle equipment.

Server consolidation greatly ameliorates the problem of underutilization of already installed servers. It creates a number of virtual server instances that reside on a smaller number of physical servers. Thus, a data center with just a few physical servers can potentially have many virtual servers, which act almost identically to the physical servers. To be sure, their capacities are less than those of the physical servers, but since those servers tend to be underutilized, this situation is not a problem. Using virtual servers, a data center can run with greater utilization, meaning lower power costs for both equipment and cooling. It also permits equipment consolidation, which simply means reducing the amount of equipment. If just a few virtualized servers can do the job of many physical servers, then implementing virtualization allows data center operators to either purchase fewer servers for new IT projects or eliminate existing servers in legacy data centers This paper discusses results taken from a case study that implements server virtualization in tier level data center. The results clearly indicate a reduction in energy consumption and increased utilization of already installed servers and other devices to lower the infrastructure load, thus a tremendous decrease in overall costs required to operate and maintain the data center.

Server consolidation was applied on all types of servers to reduce the number of physical servers and shift their workloads to fewer physical servers and measure their performance and power consumption, to discover the overall energy consumption costs applied to the data center. The results analyzed consist of a data center with 500 servers, all values before and after the installation of server consolidation were gathered, compared and analyzed to determine energy consumption before and after applying the proposed technique, and then benchmarks were set to properly measure the overall efficiency of the data center using green metrics.

5.3. Server Categorization

The proposed technique categorizes underutilized volume servers into three resource pools depending on their workloads, utilization ratio, performance, usage and applications they execute. These classifications may vary from business to business with different infrastructures and requirements, as servers are mostly used to create, maintain and execute solutions on the behalf of businesses, architectures, processes and infrastructures. These categories are:

1. Innovation Servers
2. Production Servers
3. Mission Critical Servers

5.3.1. Innovations Servers

Innovation servers are the simplest type of servers available profusely in data centers mostly installed in shared computing environments, where there is a provision of additional new servers. The applications executed by these servers require speed and flexibility and should be completed quickly. These servers are deployed at locations where there is huge potential for inventing new services, modifying existing applications and services, and for developing and enhancing processes; which are more competitive and productive. This creates space for the addition of new servers; hence their number tends to increase rapidly, without considering the proper utilization of existing servers.

5.3.2. Production Servers

These servers are much more controlled and scalable servers, deployed at locations where there is less chance of new servers being added. These servers are typically installed for testing and evaluating purposes to test applications and processes and are referred to as test, deployment or quality assurance volume servers. They are usually less in number compared to innovation servers. The service level requirements for different applications and servers are more important than speed and flexibility.

5.3.3. Mission Critical Servers

These are the most powerful servers in any data center, consuming more energy and power compared to other types of servers. They perform the most critical applications and processes and handle critical real time jobs where there are chances of loss of memory and customer loyalty. These servers are normally small in number and have a significant impact on overall business requirements.

6. Data Analysis

The use of virtualization technology in an IT portfolio improves cost per transaction, reduces some of the data center space power cooling requirements, and makes it easier to deploy resources in a fast changing environment. It promises to dramatically change how data centers operate by breaking the bond between physical servers and the resources they use. Initially servers were categorized according to the workloads they perform, applications they execute and energy they consume and then measure their consumption of energy utilization before implementing server consolidation. Annual energy consumption in different sections of data center was measured in kWh.

6.1. Energy Savings

Table 1: Pre Consolidation of Ratios of Servers and their Energy Consumption

Types of Servers	Innovation	Production	Mission Critical	Total Ratio
No of servers	250	175	75	500
Utilization	8%	12%	10%	10%
Watts per server = 100 * server count	250*100 =25000 watts	175*100 =17500 watts	75*100 =7500 watts	50000 watts

Server virtualization results in a dramatic reduction in IT power systems, almost substantially more than the cost of servers. Table 1 shows the total number of servers in the data center, their categorization along with utilization ratio and energy consumed in watts by each category of server before applying server consolidation. There was a total of 500 servers comprising three categories depending on their workloads, applications they execute and power they consume. The total utilization ratio of all servers was only 10% while each server was consuming 100 watts of power. The total power consumed by all servers was 50000 watts.

$$500 \times 100 = 50000\, watts$$

Table 1 shows the average utilization ratio of all servers was 10% before applying consolidation and every server was consuming 100 watts of power; hence the total energy consumed by all 500 servers was 50000 watts. After applying server consolidation with consolidation ratios of 7:1 for innovation servers, 5:1 for production servers and 3:1 for mission critical servers, it is observed that there is a decrease of almost half of the power consumption of these servers.

Table 2: Post-Consolidation Ratios of Servers and Their Energy Consumption

Types of Servers	Innovation	Production	Mission Critical	Total Ratio
Consolidation ratio	7:1	5:1	3:1	5:1
Post consolidation utilization	30%	30%	30%	30%
Servers after consolidation	36	35	25	96
Post consolidation energy consumption in watts	36*275 =9900 watts	35*275 =9625 watts	25*275 =6875 watts	26400 watts
Energy Saving	25000-9900 =15100 watts	9625 =7875 watts	7500-6875 =625 watts	23600 watts

Table 2 shows the average consolidation ratio for all servers after applying consolidation was 5:1. The consolidation ratios were selected on the basis of workloads and processing capabilities of these servers. The average energy consumed after applying server virtualization. Each server now consumes 275 watts of power compared to 100 watts before server consolidation. The reason for this increase in energy consumption is due to the increase in the workloads and processing capability of these servers. The total energy consumed by all servers is only 26400 watts compared to 50000 watts before applying server consolidation, while the utilization ratio has increased to almost 30% compared to an average 10%. Table 2 also shows that after applying server consolidation the total number of servers reduced to 96 compare to 500.

Table 3: Energy Saving after applying Server Consolidation

Types of Servers	Innovation	Production	Mission Critical	Total Energy
Server count	250	175	75	500
Before consolidation	25000 watts	17500 watts	7500 watts	50000 watts
After consolidation	9900 watts	9625 watts	6875 watts	26400 watts
Energy Saving	15100 watts	7875 watts	625 watts	23600 watts

Table 3 shows total energy savings by all servers. The total power consumed by all servers after consolidation was 26,400 watts as compared to 50,000 watts before applying server consolidation, with a total saving of 23,600 watts of energy, which is almost half of the total energy consumed. Moreover, if the utilization ratio is increased to 50%, then only 350 watts of energy will be consumed by every server, compared to 275 watts. There is no linear relationship between energy consumption and productivity output of a server. If a server is processing at 5% the utilization ratio and target rate is 30%, then energy consumption can reduce by almost 95%, by improving server utilization and turning off unused idle servers. Therefore this technique is very useful in implementing green energy efficient, and environment friendly data centers as energy consumption is almost reduced by half.

Above results clearly show that when servers are consolidated to an average ratio of 5:1, then there is a considerable reduction in energy consumption, i.e., 5 servers with 100 watts per server consuming a total of 500 watts. But, after consolidating, the load of these 5 servers was shifted to on average 1 server with energy consumption of only 275 watts and utilization ratio of almost 30%, thereby saving almost 225 watts, i.e., 50% of total energy. Therefore it can be computed as: 500 − 275 = 225 watts.

Thus, it is concluded that power utilization is much less consumed compared to the processor utilization ratio. Decreasing the physical servers reduces energy consumption, but also has a great impact on the overall data center heating requirements, cooling load, as well as increases UPS backup time. It also increases performance efficiency, improves generator backup times, and reduces the IT configuration of different interconnecting devices.

7. Conclusion

This paper highlights a new technique to categorize servers into three categories depending on workload and the applications they process. Server consolidation is applied on all servers so that underutilized servers can be eliminated to reduce energy consumption. The results clearly show a saving of almost 23,600 watts and at the same time achieve a utilization ratio of 30%. It is very important to characterize the workloads that need to be consolidated before applying server virtualization. It is also important to determine the type of servers, their current status whether idle or busy, how much it costs to implement server consolidation, the type of technology needed to achieve the service levels required and finally meet the security/privacy objectives. It is also vital for the data center managers to check whether they have the necessary infrastructure to handle increased power and cooling densities that arise due to the implementation of virtualization.

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