**Research Paper**

**VIRTUAL MACHINE ENERGY CONSUMPTION IN GREEN CLOUD**

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**ABSTRACT**

Traditionally, the development of computing systems has been focused on performance improvements driven by the demand of applications from consumer, scientific, and business domains. However, the ever-increasing energy consumption of computing systems has started to limit further performance growth due to overwhelming electricity bills and carbon dioxide footprints. Therefore, the goal of the computer system design has been shifted to power and energy efficiency. To identify open challenges in the area and facilitate further advancements, it is essential to synthesize and classify the research on power- and energy-efficient design conducted to date. The primary focus of designers of computing systems and the industry has been on the improvement of the system performance. According to this objective, the performance has been steadily growing driven by more efficient system design and increasing density of the components described by Moore’s law [1]. Although the performance per watt ratio has been constantly rising, the total power drawn by computing systems has hardly decreased.

Keywords: Virtual Machine, Live Migration, Performance Model, Energy.

**Introduction**

Energy consumption is not only determined by hardware efficiency, but also by the resource management system deployed on the infrastructure and the efficiency of applications running in the system. The interdependence of different levels of computing systems in regard to energy consumption is shown in Figure 2.1. Energy efficiency impacts end-users in terms of resource usage costs, which are typically determined by the Total Cost of Ownership (TCO) incurred by the resource provider. Higher power consumption results not only in boosted electricity bills but also in additional requirements to the cooling system and power delivery infrastructure, i.e., Uninterruptible Power Supplies (UPS), Power Distribution Units (PDU), and so on.

Apart from the overwhelming operating costs and the total cost of acquisition (TCA), another rising concern is the environmental impact in
terms of carbon dioxide (CO2) emissions caused by high energy consumption. Therefore, the reduction of power and energy consumption has become a first-order objective in the design of modern computing systems. The roots of energy-efficient computing, or Green IT, practices can be traced back to 1992, when the U.S. Environmental Protection Agency launched Energy Star, a voluntary labeling program designed to identify and promote energy-efficient products to reduce the greenhouse gas emissions. Computers and monitors were the first labeled products. This led to the widespread adoption of the sleep mode in electronic devices.

At that time, the term “green computing” was introduced to refer to energy efficient personal computers [8]. At the same time, the Swedish confederation of professional employees has developed the TCO certification program a series of end-user and environmental requirements for IT equipment including video adapters, monitors, keyboards, computers, peripherals, IT systems, and even mobile phones. Later, this program has been extended to include requirements on ergonomics, magnetic and electrical field emission levels, energy consumption, noise level, and use of hazardous compounds in hardware.

Energy-efficient resource management has been first introduced in the context of battery powered mobile devices, where energy consumption has to be reduced to improve the battery lifetime. Although techniques developed for mobile devices can be applied or adapted for servers and data centers, this kind of systems requires specific methods. This chapter discusses various ways of reducing power and energy consumption in computing systems, as well as recent research that deals with power and energy efficiency at the hardware and firmware, Operating System (OS), virtualization, and data center levels. The objectives of this chapter is to give an overview of the recent research advancements in energy-efficient computing, classify the approaches, discuss open research challenges, and position the current thesis within the research area.

**Different Energy Models**

To understand power and energy management mechanisms, it is essential to clarify the terminology. Electric current is the flow of electric charge measured in amperes. Amperes define the amount of electric charge transferred by a circuit per second. Power and energy can be defined in terms of work that a system performs. Power is the rate at which the system performs the work, while energy is the total amount of work performed over a period of time. Power and energy are measured in watts.
(W) and watt-hour (Wh), respectively. Work is done at the rate of 1 W when 1 A is transferred through a potential difference of 1 V. A kilowatt-hour (kWh) is the amount of energy equivalent to a power of 1 kW (1000 W) being applied for one hour.

The difference between power and energy is very important since a reduction of power consumption does not always reduce the consumed energy. For example, power consumption can be decreased by lowering the CPU performance. However, in this case, a program may take longer to complete its execution consuming the same amount of energy. On one hand, a reduction of peak power consumption results in decreased costs of the infrastructure provisioning, such as costs associated with capacities of UPS, PDU, power generators, cooling system, and power distribution equipment. On the other hand, decreased energy consumption reduces the electricity bills.

Energy consumption can be reduced temporarily via Dynamic Power Management (DPM) techniques, or permanently applying Static Power Management (SPM). DPM utilizes the knowledge of the real time resource usage and application workloads to optimize energy consumption. However, it does not necessarily decrease peak power consumption. In contrast, SPM prescribes the usage of highly efficient hardware components, such as CPUs, disk storage, network devices, UPS, and power supplies. These structural changes usually reduce both energy and peak power consumption.

Sources Of Power Consumption

According to data provided by Intel Labs [10], the main part of power consumed by a server is accounted for the CPU, followed by the memory and losses due to the power supply inefficiency. The data show that the CPU no longer dominates power consumption by a server. This resulted from the continuous improvements of the CPU power efficiency combined with power-saving techniques (e.g., DVFS) that enable active low-power modes. In these modes, a CPU consumes a fraction of the total power, while preserving the ability to execute programs. As a result, current desktop and server CPUs can consume less than 30% of their peak power in low-activity modes, leading to dynamic power ranges of more than 70% of the peak power [10].

In contrast, dynamic power ranges of all the other server components are much narrower: less than 50% for Dynamic Random Access Memory (DRAM), 25% for disk drives, 15% for network switches, and negligible for other components [11]. The reason is that only the CPU supports active low-power modes, whereas other components can only be
completely or partially switched off. However, the performance overhead of a transition between the active and inactive modes is substantial. For example, a disk drive in the deep-sleep mode consumes almost no power, but a transition to the active mode incurs a latency 1000 times higher than the regular access latency. Power inefficiency of the server components in the idle state leads to a narrow overall dynamic power range of 30%: even if a server is completely idle, it still consumes more than 70% of its peak power.

Another reason for the reduction of the fraction of power consumed by the CPU relatively to the whole system is the adoption of multi-core architectures. Multicore processors are substantially more efficient than conventional single-core processors. For example, servers built with recent Quad-core Intel Xeon processor can deliver 1.8 teraflops at the peak performance, using less than 10 kW of power. To compare with, Pentium processors in 1998 would consume about 800 kW to achieve the same performance [6].

The adoption of multi-core CPUs along with the increasing use of virtualization and data-intensive applications resulted in the growing amount of memory in servers. In contrast to the CPU, DRAM has a narrower dynamic power range, and power consumption by memory chips is increasing. Memory is packaged in dual in-line memory modules (DIMMs), and power consumption by these modules varies from 5 to 21 W per DIMM for the DDR3 and fully buffered DIMM (FB-DIMM) memory technologies [6]. Power consumption by a server with eight 1 GB DIMMs is about 80 W.

Modern large servers currently use 32 or 64 DIMMs, which leads to power consumption by the memory being higher than by the CPUs. Most of power management techniques are focused on the CPU; however, the constantly increasing frequency and capacity of memory chips in addition to the problem of high energy consumption raise the cooling requirements. These facts make memory one of the most important server components that has to be efficiently managed.

Power supplies transform alternating current (AC) into direct current (DC) to feed the server components. This transformation leads to significant power losses due to the inefficiency of the current technology. The efficiency of power supplies depends on their load. They achieve the highest efficiency at loads within the range of 50-75%. However, most data centers normally create a load of 10-15% wasting the majority of the consumed electricity and leading to the average power losses of 60-80%. As a result, power supplies consume at least 2% of the US electricity production [6].
More efficient power supply design can save more than a half of energy consumption. The problem of the low average utilization also applies to disk storage, especially when disks are attached to servers in a data center. However, this can be addressed by moving the disks to an external centralized storage array. Nevertheless, intelligent policies are required to efficiently manage a storage system containing thousands of disks.

**Accounting**

To evaluate our approach of distributed energy accounting, we measured the overall energy required for using a virtual disk. For that purpose, we ran a synthetic disk stress test within a Linux guest OS. The test runs on a virtual hard drive, which is multiplexed on the physical disk by the disk driver VM. The test performs almost no computation, but generates heavy disk load. By opening the virtual disk in raw access mode, the test bypasses most of the guest OS’s caching effects, and causes the file I/O to be performed directly to and from user space buffers. Afterwards, the test permanently reads (writes) consecutive disk blocks of a given size from (to) the disk, until a maximum size has been reached. We performed the test for block sizes from 0.5 KByte up to 32 KByte. We obtained the required energy per block size to run the benchmark from our accounting infrastructure.

**Conclusion**

We see our work as a support infrastructure to develop and evaluate power management strategies for VM-based systems. We consider three areas to be important and prevalent for future work: devices with multiple power states, processors with support for hardware-assisted virtualization, and multi-core architectures. There is no design limit with respect to the integration into our framework, and we are actively developing support for them.

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