

Energy Efficiency of Server Virtualization

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Abstract—The need for computing power keeps on growing. The rising energy expenses of data centers have made server consolidation and virtualization important research areas. Virtualization and its performance have received a lot of attention and several studies can be found on performance. So far researches have not studied the overall performance and energy efficiency of server consolidation. In this paper we study the effect of server consolidation on energy efficiency with an emphasis on quality of service. We have studied this with several synthetic benchmarks and with realistic server load by performing a large set of measurements. We found out that energy-efficiency depends on the load of the virtualized service and the number of virtualized servers. Idle virtual servers do not increase the consumption much, but on heavy load it makes more sense to share hardware resources among fewer virtual machines.

Keywords-virtualization; energy-efficiency; server consolidation; xen; kvm; invenio; cmssw

I. INTRODUCTION

The need for computing power in data centers is heavily growing due to cloud computing. Large data centers host cloud applications on thousands of servers [1], [2]. Traditionally, servers have been purchased to host one service each (e.g., a web-server, a DNS server). According to many studies the average utilization rate of a server is around 15% of maximum but depends much on the service and it can be even as low as 5% [3], [4].

This level of utilization is very low compared to any field in industry. A common explanation for the low utilization is that data centers are build to manage peak loads. However, this is not a new data center specific issue, since high peak loads are common in many other fields. Even with this low level of utilization the computers are usually operational and consuming around 60% of their peak power [5]. Low utilization level is inefficient through the increased impact on infrastructure, maintenance and hardware costs. For example, low utilization reduces the efficiency of power supplies [6] causing over 10% losses in power distribution. Thus, computers should run in near full power when they do value adding work, because then they operate most efficiently when comparing consumed energy per executed task [3].

A solution for increasing utilization is server consolidation by using virtualization technologies. This enables us to

combine several services into one physical server. In this way, these technologies make it possible to take better advantage of hardware resources.

In this study, we focus on energy efficiency of different virtualization technologies. Our aim is to help the system administrator to decide how services should be consolidated to minimize energy consumption without violating quality of service agreements.

We studied energy consumption of virtualized servers with two open source virtualization solutions; KVM and Xen. They were tested both under load and idle. Several synthetic tests were used to measure the overhead of virtualization on different server components. Also a couple of realistic test cases were used; an Invenio database service and CMSSW, The CMS Software Framework, physics analysis software. The results were compared with the results of the same tests on hardware without virtualization. We also studied how overhead of virtualization develops by sharing resources of physical machines equally among different number of virtual machines and running the same test set on each virtual machine set.

II. RELATED WORK

Virtualization and its performance is a well-studied area but these studies mainly focus on performance, isolation, and scheduling. Even though energy efficiency is one of the main reasons for server consolidation and virtualization, it has not received much attention. Many of these studies evaluate overhead differences between different virtualization solutions.

Regola et al. studied the use of virtualization in high performance computing (HPC) [7]. They believed that virtualization and the ability to run heterogeneous environments on the same hardware would make HPC more accessible to bigger scientific community. They concluded that the I/O performance of full virtualization or para-virtualization is not yet good enough for low latency and high throughput applications such as MPI applications.

Nussbaum et al. [8] made another study on the suitability of virtualization on HPC. They evaluated both KVM and Xen in a cluster of 32 servers with HPC Challenge benchmarks. These studies did not find a clear winner.

They concluded the performance of full virtualization is far behind that of paravirtualization. Also running workload among different number of virtual machines did not seem to have an effect. Verma et al. [9] also studied the effect of having the same workload on different number of virtual machines. They found out that virtualization and division load between several virtual machines does not impose significant overhead.

Padala et al. [10] carried out a performance study of virtualization. They studied the effect of server load and virtual machine count on multi tier application performance. They found OS virtualization to perform much better than paravirtualization. The overhead of paravirtualization explained by L2 cache misses, which in the case of paravirtualization increased more rapidly when load increased.

Another study from Deshane et al. [11] compare scalability and isolation of a paravirtualized Xen and a full virtualized KVM server. Results said that Xen performs significantly better than KVM both in isolation and CPU performance. Surprisingly, a non-paravirtual system outperforms Xen in I/O performance test.

As we can see from previous work, the energy-efficiency has not received much attention. Our study focuses mainly on the energy-efficiency of virtualization.

III. TESTS AND TEST ENVIRONMENT

Our tests aimed at measuring the energy consumption and overhead of virtualization with a diverse test set. We used both synthetic and real applications in our tests and measured how performance is affected by virtualization. We compared the results of the measurements, that were done on virtual machines, with the results of the same tests on physical hardware. First we measured the idle consumption of virtualized machines using different number of virtual machines. Then we compared different virtualization technologies and operating systems.

A. Test Hardware

The tests were conducted in our dedicated test environment. The test computer was a Dell PowerEdge R410 server with two Intel Xeon E5520 processors and 16 GB of memory. Hyper-threading was disabled for the processors and clock speed was the default 2.26 GHz for all cores. The Turbo Boost option of Intel was enabled. The system had a single 250 GB hard disk drive. As a client computer we used a server with dual Xeon processors running at 2.80 GHz. Network was routed through D-Link DGS-1224T gigabit routers. Power usage data was collected with a Watts up? PRO meter via a USB cable. Power usage values were recorded every second. For physics analysis tests (CMSSW) and some idle tests, we used a dual processor Opteron 2427 server with 32GB of memory and 1 TB hard disk.

B. Used Virtualization Technologies

The operating system used in all machines, virtual or real, was a standard installation of 64-bit Ubuntu Server 10.04.3 LTS. The same virtual machine image was used with both KVM and Xen guests. The image was stored in a raw format, i.e., a plain binary image of the disc image. We used the Linux 3.0.0 kernel. It was chosen as it had the full Xen hypervisor support. With this kernel we were able to compare Xen with KVM without a possible effect of different kernels on performance.

For CMSSW tests, a virtual machine with Scientific Linux 5 was installed with CMSSW version 4.2.4. For these tests real data files produced by the CMS experiment was used. These data files were stored on a Dell PowerEdge T710 server and shared to the virtual machines with a network file system, NFSv4.

C. Test Applications

Our synthetic test collection consisted of Linpack [12], BurnInSSE¹, Bonnie++ [13] and Iperf [14]. Processor performance was measured with an optimized 64-bit Linpack test. This benchmark was run in sets of thirty consecutive runs and power usage was measured for whole sets. In addition, processor power consumption measurements were conducted with ten minute burn-in runs with 64-bit BurnInSSE collection using one, two and four threads. Disk input and output performance was measured using Bonnie++ 1.96. The number of files for a small file creation test was 400. For a large file test the file size was 4 GB. For Bonnie++ tests, the amount of host operating system memory was limited to 2.5 GB with a kernel parameter and the amount of guest operating system memory was limited to 2 GB. For hardware tests, a kernel limit of 2 GB was used. The tests were carried out ten times. Network performance was measured using Iperf 2.0.5. Three kinds of tests were run: one where the test computer acted as a server, another where it was the client and a third where the computer did a loopback test with itself. Testing was done using four threads and a ten minute timespan. All three types of tests were carried out five times.

As real world applications, we used two different systems. The first one was based on the Invenio document repository [15]. We used an existing Invenio installation, which had been modified for the CERN library database. The Invenio document repository software suite was v0.99.2. The document repository was run on an Apache 2.2.3 web server and a MySQL 5.0.77 database management system. All this software were run on Scientific Linux CERN 5.6 inside a chroot environment. Another server was used to send HTTP requests to our test server. The requests were based on an anonymous version of a real-life log data from similar document repository in use at CERN. The requests were sent

¹<http://www.roylongbottom.org.uk>

using the Httperf web server performance test application [16].

The second real application was a physics data analysis that used the CMSSW framework [17]. This analysis task is a very typical one in high-energy physics. We used real data created at CERN. The data was stored in a ROOT image[18] files, which our case were of size 4GB. Normally, a data analysis with this data takes days to perform, thus we limited the number of events of one analysis task to 300. With this limitation the analysis takes 10 minutes on the Opteron hardware. The data was located on network file system, NFS, and reading it caused very little network traffic, 2kB per task.

IV. RESULTS

A. Idle consumption

First we studied idle energy consumption with different virtualization solutions and with different number of virtual machines. We also tested the effect of having different operating systems in virtual machines.

Figure 1 shows the power consumption of two different virtualization solutions. We had three virtual machines running idle in both cases. The figure shows how energy consumption of two different virtualization solutions behave when the servers are idle. It shows how overhead of virtualization depends on the virtualization solution and kernel version. The difference between KVM and hardware is less than 3%, which is already a big improvement compared to three separate physical machines running idle. This test was run with the Dell R410 server.

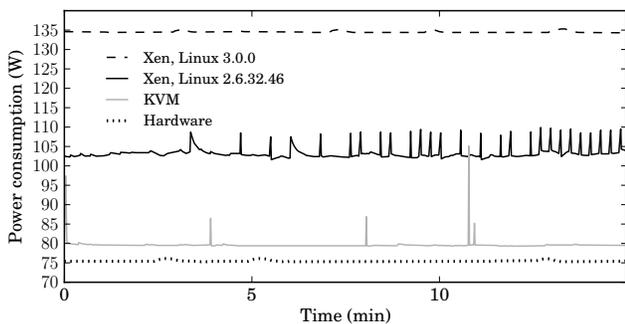


Figure 1. Typical idle power consumption

The second idle measurement was run on the dual processor Opteron server. Test measured the energy consumption of the physical hardware for 20 minutes. Figure 2 shows how the operating system affects the idle consumption. The same test was repeated with different number of virtual machines on the same physical hardware. The energy consumption cumulates with the virtual machine count when we have Scientific Linux 5 (SLC5) but with Ubuntu it remains almost the same as hardware.

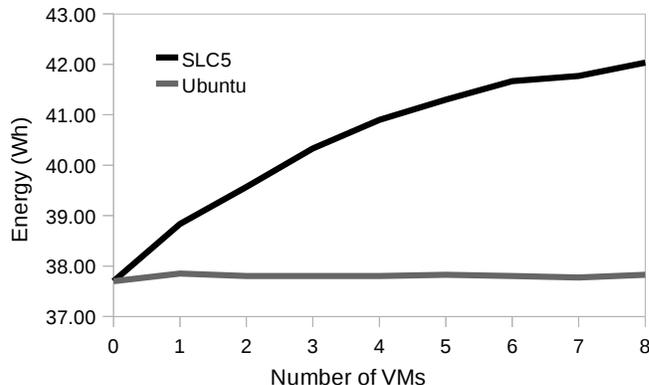


Figure 2. Energy consumption of idle virtual machines

B. Synthetic tests

We used synthetic tests to stress different server components; CPU, I/O and network. With these tests we studied in which situations virtualization causes the most overhead.

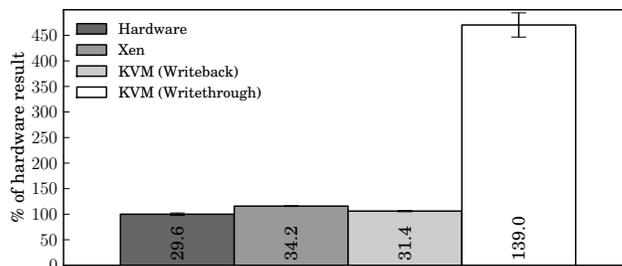


Figure 3. The energy consumption of Bonnie++ (Wh)

As seen in Figure 3, when running a set of synthetic disk operations Xen uses slightly more energy compared to hardware. With KVM the situation is different. When using the default writethrough cache, KVM uses around 350% more energy than hardware. About 90% of the test time is spent doing the small file test part of Bonnie++. Switching to writeback cache, results of KVM are actually slightly better than hardware results. Writeback cache writes only to a cache and stores data to the disk only just before the cache is replaced. This is a cache mode that is not safe for production use and is available mainly for testing purposes.

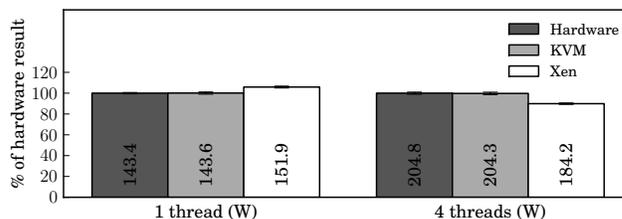


Figure 4. Power consumption under high CPU load with BurnInSSE

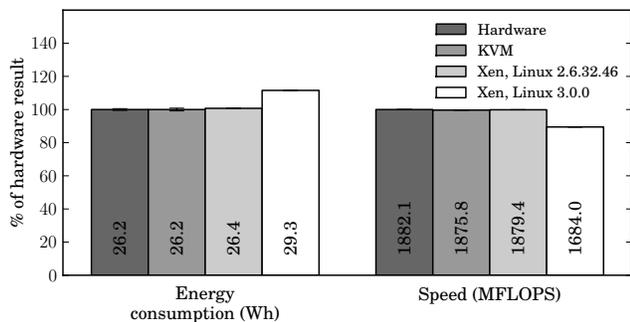


Figure 5. Energy consumption under high CPU load with Linpack

In Figure 4, power consumption is tested under full CPU load between 1 and 4 threads running BurnInSSE64. With 1 thread, KVM and hardware use the same amount of power, but Xen uses around 10% more. With 4 threads the situation is the other way around: Xen uses less power than KVM and hardware. The explanation to this can be seen in Figure 5. Even though Xen uses more power in the single-threaded LINPACK test, it is slower: the CPU is not running at its full turbo boosted speed, but Xen has a systematic overhead in power consumption compared to the others. With 4 threads, Xen’s CPUs are not running at full speed so the power usage is not so great as with hardware or KVM, and the effect of overhead in power consumption is overshadowed by the power usage of 4 computing threads.

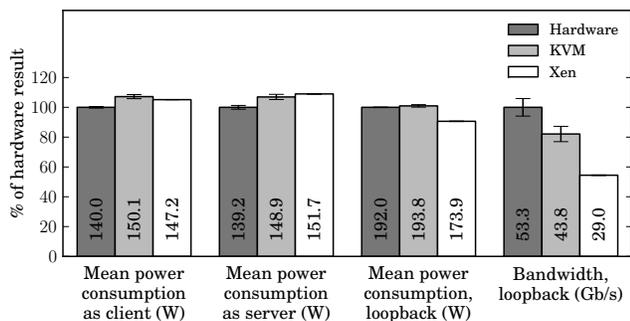


Figure 6. Power consumption under Iperf network traffic test

Iperf test results in Figure 6 show a similar trend: KVM uses slightly more power than hardware while Xen consequently uses slightly more power than KVM. Interestingly, when a Xen virtual machine was running as server it used slightly more power than when running as client. With KVM and hardware it was the other way around. In the loopback mode, one can find similar results with Xen as in the LINPACK test in Figure 5: for some reason, Xen’s performance is capped and consequently bandwidth in the loopback mode is much worse than with KVM or hardware, and on the other hand mean power consumption is lower.

C. Realistic load

Realistic tests were designed such that we would get better understanding of energy usage in two different real world situations: web services and physics analysis.

The first realistic test was a CERN document server repository case. In this test, we sent HTTP requests, which were based on CERN library log data, to a virtualized web server. We measured both performance and power consumption. We ran the same test with and without virtualization. We compared two virtualization solutions and hardware to measure the overhead of virtualization. In all Invenio tests, the Invenio installation was in a chroot environment with a complete SLC5 installation. To assure that chroot between the operating system and the Invenio web application did not have any negative effects on test results, a comparative test was performed between the base system and another chroot environment using a copy of the base system as the new root.

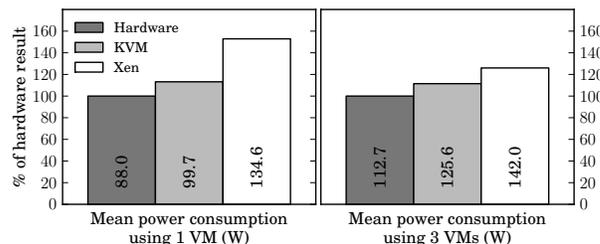


Figure 7. Power consumption of different virtualization solutions with different number of virtual machines in the repository test

In Figure 7, we have the results for Httpperf rates 5 and 15. On the left side we have one virtual machine with rate 5 workload and on the right side 3 virtual machines with load 5. It shows the power consumption levels when we have more virtual machines and load.

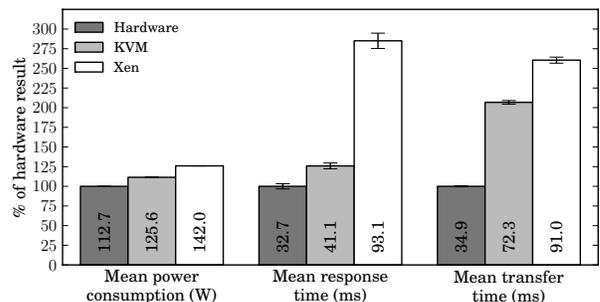


Figure 8. Power consumption and Httpperf results of different virtualization solutions

Figure 8 shows the results of comparison of hardware, Xen and KVM with different number of virtual machines.

We tested overhead of virtualization by increasing the number of virtual machines with similar workload. These

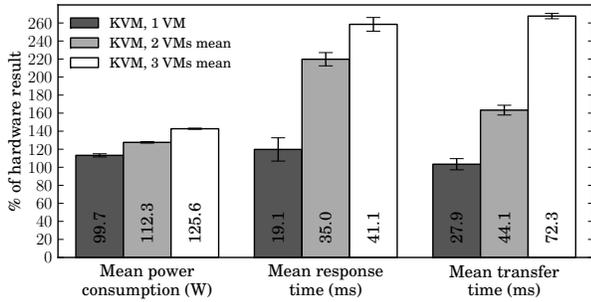


Figure 9. The effect of workload on virtual machine performance with KVM using different amounts of virtual machines

results are illustrated in Figure 9

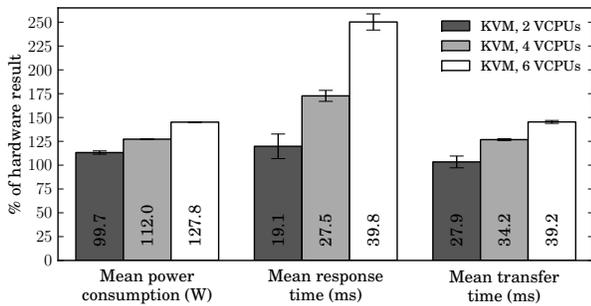


Figure 10. The effect of workload on virtual machine performance with KVM using different virtual machine resources

In Figure 10, we have the results of a test where, instead of growing the number of virtual machines, we increased the load and resources of one virtual machine. Table IV-C shows the rates and resources given to virtual machines in these tests. The MaxClients setting refers to the maximum clients setting in Apache web server configuration.

Table I
SETTINGS FOR CHANGING LOAD AND RESOURCES OF A SINGLE VIRTUAL MACHINE

VCPUs	Memory (GB)	MaxClients	Request rate
2	5	8	5
4	8	15	10
6	15	24	15

Figures 11 and 12 illustrate the effect of virtualization on quality of service. They show a cumulative distribution of response times the Httpperf test application reported for the HTTP requests.

In Figure 11, we have the results of running workload of 15 queries per second on 3 virtual machines and on hardware for comparison. Corresponding performance results are shown in Figure 8. These figures show how the response times increase when the same workload is divided into 3 virtual machines.

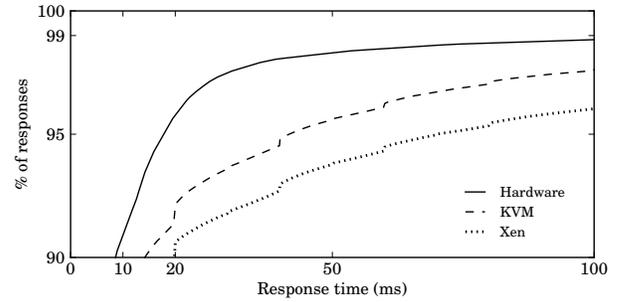


Figure 11. The impact of virtualization solution on quality of service

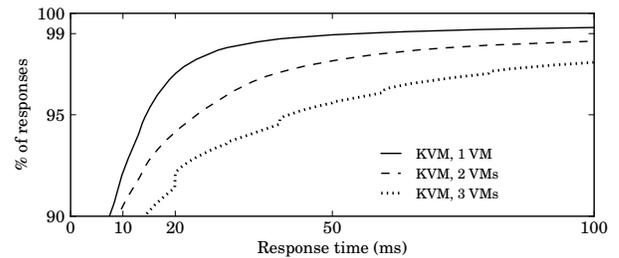


Figure 12. The impact of different loads on quality of service

To better show the virtualization overhead effect on different workload and number of virtual machines we compared KVM with rates 5, 10, and 15. The results of this experiment can be seen in Figure 12. Corresponding performance measurements are shown in Figure 9.

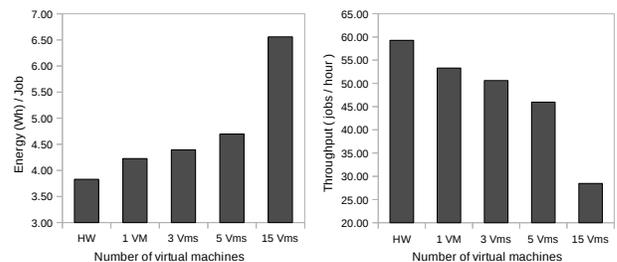


Figure 13. Running 15 jobs in different number of virtual machines

As our second realistic load, we had a physics analysis application. Here we consider one run of the test application as a job. In Figure 13, we have the results of running 15 jobs in 5 different virtual machine sets. The figure illustrates how the energy efficiency degrades as the number of virtual machines increases. 15 virtual machines running one job is 6.8 times less energy efficient than running 15 jobs on one virtual machine.

Figure 14 shows the effect of workload on energy-efficiency. We tested different workloads on 5 identical virtual machines sharing the the same physical server.

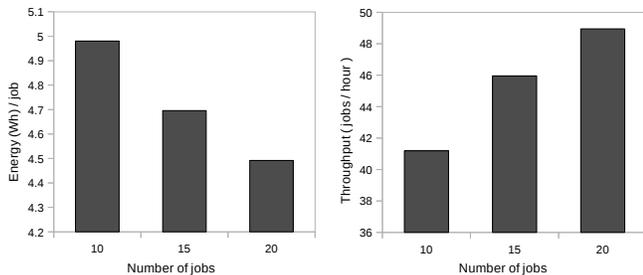


Figure 14. Running different workload on 5 virtual machines

V. CONCLUSIONS

The overhead of virtualization is a well-known fact reported in many publications. Although the technologies have been improving a lot during the past five years, the performance of a virtualised system is still far from the hardware level. However, this does not mean that virtualization could not be useful in improving energy-efficiency in large data centers but it means that one should know how to apply this technology to achieve savings in energy consumption.

We studied the energy-efficiency virtualization technologies and how different load affects it. Our research indicates that idle power consumption of virtualized server is close to zero. However, this depends a lot on the operating system running on the virtual machine, but it is always a small number compared to idle energy consumption of a physical server. Our study also indicates that virtualization overhead has great impact on energy-efficiency. This means that it would make more sense to share the physical resources among few virtual machines with heavy load instead of larger set of light-loaded ones.

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