Energy Efficiency Measurements of Mobile Virtualization Systems

Marius Marcu and Dacian Tudor

"Politehnica" University of Timisoara
2 V. Parvan Blv, 300223 Timisoara, Romania
{mmarcu,dacian}@cs.upt.ro

Abstract. The energy efficiency has become an important aspect in data centers and large server systems, including the ones used in infrastructure for mobile applications service providers. Virtualization is one of the main research directions for both large scale data centers and applications servers. Furthermore, virtualization is also popular on desktop systems and is now considered in embedded systems. The next step will be to use virtualization on battery powered systems or mobile devices, where power consumption is an important aspect. This paper explores how virtualization influences the power consumption of both physical systems and virtual systems and which is the most efficient way to implement virtualized applications. The paper proposes a test bench and a set of test cases which can be further used to evaluate and compare different virtualization solutions together with several power management mechanisms using specific energy efficiency metrics.

Keywords: consumption, energy efficiency, virtualization, virtual machine.

1 Introduction

We have been witnessing the development of enterprise servers and data centers to support cloud computing for the last few years. The design of data and computing centers implies a tradeoff between performance and power consumption. The main requirement for these solutions is to provide the agreed level of services while trying to minimize the service provisioning costs [1]. Power consumption is a critical parameter in modern datacenter and enterprise environments, since it directly impacts both the deployment costs (peak power delivery capacity) and operational costs (power supply, cooling) [2]. One solution for power consumption reduction is to consolidate multiple servers running in different virtual machines (VMs) on a single physical machine (PM) which increases the overall utilization and efficiency of the equipment across the whole deployment. [3]

On the other hand we assist to an increasing development of mobile applications and services intended for various types of mobile devices. This trend will influence other areas, including the cloud computing solutions. Cloud computing support for mobile applications is identified as a new direction of research and development. Although several research works have been conducted in the field of cloud computing

R. Prasad et al. (Eds.): MOBISEC 2011, LNICST 94, pp. 88–100, 2012.

for mobile technologies, this field is vastly unexplored [5]. Cloud computing for mobile applications and service, called Mobile Cloud Computing is a well-accepted concept that aims at using cloud computing techniques for storage and processing of data on mobile devices, thereby reducing their limitations [5]. Several characteristics make mobile applications special related to other types of applications executed in the cloud: large number of users, devices with small amount of resources, forward complex operations to run on the cloud, different usage pattern, security services, etc. Therefore we can say that mobile devices will be prepared in near future to implement specific virtualization solutions.

Our main research goal is to investigate the energy efficiency of virtualization solutions in battery powered computing systems. The paper proposes a test bench and a set of test cases which can be further used to evaluate and compare different virtualization solutions together with several power management mechanisms using specific energy efficiency metrics. In our current tests we investigate energy efficiency of several algorithms or benchmarks (memory, IO and CPU) and different user applications. We execute the proposed tests on a dual-core laptop with L4 Linux paravirtualization solution.

Section 2 of this paper contains a brief look at energy efficiency of virtual platforms and specific power management mechanisms available for VMs. In section 3 we define the evaluation methodology used in our tests to show the power consumption and energy efficiency of virtual systems. In section 4 we present the results we obtained for power consumption and energy efficiency proposed test cases.

2 Power Management of Virtualized Solutions

A cornerstone in the energetically evaluation for virtualized systems is the measurement procedure and context for both physical systems and virtual machines. Power consumption of physical servers is an important metric used when evaluating different virtualized solutions implemented on top of these servers. The power consumption issue of computing systems is in general a very complex one because every physical component in the physical system has its own power consumption profile depending especially on its execution workload. In virtualized environments the power consumption modeling problem is much more complex because software applications are running on VMs and they do not access directly the physical components. The host operating system has to provide access to physical components and share these components for different VMs and their applications. The nature of workload executed in each VM determines the power profile and performance of the VM, and hence its energy consumption [2]. The complexity of measuring energy efficiency for virtualized systems is increasing with the number of elements that should be addressed (e.g. number of VMs, OS, PM, power management mechanisms activated, software applications running on VMs).

The author of [1] proposed and performed a set of virtualization performance tests for three types of Intel multi-core based servers in order to estimate whether their virtualization can deliver significant benefits in data centers over non-virtualized servers. During the performance tests overall power consumption was measured and power consumption per workload was computed in order to determine the costs of providing the requested level of performance. Virtualization enables one to consolidate multiple workloads onto each server, increasing utilization and reducing power consumption per workload [1]. A CPU intensive complex database application was used as testing workload, and they progressively increased the number of virtualized workloads. In our approach we use three types of simple operations as workload in order to address the main components of the system: CPU, memory and I/O.

Another important element in energy efficiency evaluation for virtualized systems is related to the power management mechanisms and their implementations. The authors of [2] presented a multi-tier software solution for energy efficiency computing in virtualized environments based on the characteristics of the workloads co-located on the same PM. The paper shows that co-location of VMs with heterogeneous characteristics on same PM is beneficial for overall performance and energy efficiency. In [7] the authors investigate the design, implementation, and evaluation of a power-aware application placement controller in the context of an environment with heterogeneous virtualized server clusters. Their solution dispatches applications to different VM or PM taking in account performance requirements, migration costs and power consumption. The tests and experiments were executed based on the traces obtained from server farm of a large data center.

In [4] specific work related to power management of virtualized OS is presented. The authors tried to map virtual ACPI power states of VM components (e.g. CPU P-states, OS S-states and devices D-states) to real power states of the PM in order to increase the efficiency of overall power management mechanism. Nathuji and Schwan explored in their work how to integrate power management mechanisms between VMs and host PM while keeping isolation between them [6]. They proposed and implemented a software solution called VirtualPower which extends the VM power states and assign specific power policies to these states. Their main challenge is again to map VM power states to real power states of the PM.

The authors of [8] focused their research work to power management of I/O disk operations in virtualized environments. This paper presents three proposed improvements to address the disk's device drivers' power states mapping between VM and PM, based on the statistics of I/O activities between PM and VM. Their solutions are based on different combinations between buffering mechanism in the PM that buffers writes from the VMs and early flush mechanism that flushes the dirty pages from the guest OS buffer caches prior to putting the disk to sleep.

A major challenge in computer systems is the coexistence of real-time and non-real-time applications on the same machine. The authors of [9] describe the microkernel architecture of L4 and which provides both virtualization and real-time support. On a real-time capable microkernel, all applications are temporally isolated and can execute with real-time guarantees even they are virtualized. L4 Linux is a paravirtualization solution which requires changes in the guest operating systems in order to run in user space of the CPU. The changes are required in platform-specific code of Linux but all other code and device drivers are unchanged. L4 Linux was ported on IA-32 and ARM processors architectures; therefore it may be used in the near future on next multi-core mobile devices.

3 Energy Efficiency Virtualization Evaluation Methodology

In this section we describe the evaluation methodology we propose to estimate energy efficiency of virtualization solution implemented on different physical computing systems. The proposed methodology describes two aspects: evaluation test bench and evaluation test cases. First, the evaluation test bench contains the testing setup used to collect power consumption and workload performance data, to control the workload execution sequence and to provide support for energy efficiency computation and analysis. Second, the evaluation test cases specify the workload applications and configurations scenarios used to emphasis the effect of virtualization over the physical guest system power consumption.

The proposed evaluation methodology describes a standard way to evaluate power consumption and energy efficiency of VMs running on different common hardware. This methodology can be further used to compare energy data for various combinations of physical hardware, operating systems and virtualization solutions.

3.1 Evaluation Test Bench

The proposed test bench is used for power consumption and energy efficiency evaluation of L4 Linux microkernel based virtualization solutions. Test bench description contains the physical hardware systems where the VMs are running, the operating systems installed on these physical and VMs and the power measurement devices (Fig. 1).

Experimental evaluation of system virtualization power consumption uses standard multicore desktop and laptop hardware. Hardware test configuration contains two different machines, both running Ubuntu Linux and L4 Linux:

(1) HP Compaq dc7800 desktop with Intel Core2 Quad 2.4 GHz CPU, 4 GB of memory and 400 GB hard disk, and

(2) HP EliteBook 8530w laptop with Intel Core2 Duo 2.53 GHz processor, 2 GB of memory and 140 GB hard disk.

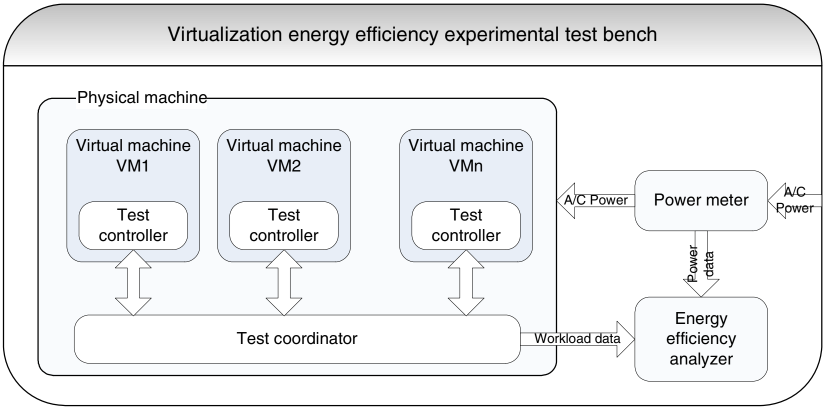

Fig. 1. Overall evaluation setup architecture

Physical machines under tests have both host operating system and virtualization system installed in order to test energy efficiency of workload operation in both PM and VM. Power measurements are considered in both absolute values and relative values to the idle state power consumption. Power measurements for both desktop and laptop systems were obtained using Watts up? series power meters. Power consumption of the entire physical hardware is measured on A/C power lines. Power measurements were obtained with a sampling rate of one per second and were saved in log files for further offline analysis. The Watts up power meter logged power values locally thereby avoiding undesirable measurements effects on the machine under test.

3.2 Evaluation Test Cases

The overall power consumption of the whole device is composed of power consumption of every device's component and the software applications running on that device. Based on this assumption we consider that software applications have a certain level of power consumption. In our proposed tests we try to estimate power consumption of physical system when the virtualization solution is running a number of workloads. Both virtualization solution and workload tests are software applications which have to be estimated from the energy perspective. Power consumption of software applications are hard to estimate or compute due to their uncertainty and interference with other running applications. Therefore we need a standard set of test cases which can be run in order to obtain an estimation of virtualization power consumption and energy efficiency with good accuracy and low measurements dispersion.

During each phase of the test case the power measures are achieved with a rate of one per second and the minimum and average power values are accounted. Every interval in the test profile lasts for a certain amount of time (e.g. 5 to 10 minutes) when no other applications, user inputs or communications are allowed. Also during the test, power management transitions are prevented to occur in order to measure exactly the workload under test. Every test is executed directly on the PM and on the virtual machine. The test execution is coordinated by a central component running on the PM (Fig. 1). This test coordinator establish a connection with all VMs in the system and start the test sequence within every VM according with the test case selected pattern.

When the test workload is running other system's parameters are read and saved in log files. CPU parameters like CPU usage, cores usage and cores temperatures are some parameters we also logged during the tests. We tried also to extract specific performance information for the workload phase in order to compute power efficiency for every executed test. The results obtained when tests are ran show how power consumption of PM varies during workload execution relative to the idle state power consumption. The workload could be executed on PM or VM. When the same test is ran more than once in the same conditions (e.g. PM or VM), the same power profile was obtained.

The data logged during test execution are analyzed offline based on power signature plotted from these data and further power levels and power efficiency values are computed for each test.

Idle State Physical System Power Consumption

The first test case we run on every system under test was introduced to estimate power consumption of the physical system when running in idle state when no power management profile is selected on the host operating system. We consider that the system idle power consumption is important in because the workloads' power consumption introduced in the next test cases will be estimated compared with this initial value. We name this test case IDLE_PHY.

The conditions specified for IDLE_PHY are related to running operating system and external environment test parameters. Therefore we ran this test on Ubuntu Linux and L4 Linux for every physical system in order to see the effect of the installed operating system on power consumption of physical system when running in idle state. External conditions, like test environment temperature, have also influence on physical system's power consumption therefore we tried to execute similar test in the same conditions.

Idle State Virtual Machines Power Consumption

The second test case we called IDLE_VM is specified to estimate power consumption of the physical system when running one or more VMs in idle state under different configuration parameters. With this test case we consider the two operating systems Ubuntu and L4 Linux in order to see the system's power consumption increase when certain virtualization solution is started. During first two tests no workload application was executed. The conditions specified for IDLE_VM are: number of VMs started and their parameter settings, the number of CPU cores and the size of RAM allowed for one VM.

CPU Workload Virtual Machines Power Consumption

The third test case we called CPU_VM is specified to estimate power consumption of the physical system when running one or more VMs and each VM executes certain workload. This test case tries to estimate how physical system's power consumption varies with different types of CPU workloads or bench-marks when running on one or more VMs compared to running directly on the physical system. For the workload phase of the test sequence we used different CPU and memory benchmarks: integer, memory and floating point. Every test execution was parameterized with the following settings: the number of VM instances, the running VM settings (CPU cores and memory size), and the number of simultaneous workload instances (processes or threads). Every test case was executed once on the physical system and then on the selected VMs. For every workload benchmark we logged also its performance data in order to estimate the energy efficiency for every test condition.

IO Workload Virtual Machines Power Consumption

The forth test case we called IO_VM is specified to estimate power consumption of the physical system when running one or more VMs each executing an IO workload. With this test case we try to show how virtualization influences the IO operations.

One important aspect we want to cover with this test case is hard disk I/O workload using existing disk benchmarks (therefore we may further refine this test case and name it DISKIO_VM). Other IO_VM test cases could also be implemented like USB, video, sound, etc. In our test we ran only DISKIO_VM test cases using a disk benchmark, parameterized with the following settings: the number of VM instances, the running VM settings (CPU cores and memory size), and the number of simultaneous workload instances (processes or threads).

User Applications Virtualization Power Consumption

The last test case we called USER_VM is specified to estimate power consumption of the physical system when one or more VMs are started each running the same user application. The test results are then compared with the measurements obtained when the selected user application is executed on the PM. The workload applications proposed for this test case are video player and file compressor.

4 Experimental L4 Linux Tests Results

In this section we show the results for the proposed test cases executions obtained for L4 Fiasco microkernel implementation.

4.1 Idle State Power Consumption

In this test the idle power consumption of PM was measured both for Ubuntu Linux operating system and L4 Linux microkernel. During the test execution we measured power consumption of the physical system when running in the following three conditions: (1) Ubuntu OS with X Windows graphical interface running, (2) Ubuntu OS with X Windows graphical interface stopped, and (3) L4 microkernel with X Windows graphical interface stopped.

The measured power values are shown in Table 1. It can be observed that when the X Windows system is running the physical system consumes ~0.8 W more power than when it is stopped. The measured power of the system when L4 is running is lower than the one measured when only the Ubuntu OS without X Windows interface is running. L4 has ~2% reduction in power consumption when running in idle mode.

Table 1. Idle power consumption measurements

System (1)	**Ubuntu X Win**	**Ubuntu Console**		**L4 Linux Console**	
AVERAGE	76.83 W	76.01 W	-1.07 %	74.50 W	-1.98 %
MINIMUM	76.60 W	75.90 W	-0.91 %	74.40 W	-1.98 %
System (2)					
AVERAGE	28.2 W	28.01 W	-0.67 %	27.50 W	-1.82 %
MINIMUM	28.1 W	27.90 W	-0.71 %	27.40 W	-1.79 %

The next presented tests results are taken for the console version of both Ubuntu OS and L4 Linux installations. We run our tests without X Windows system in order to reduce the influence of other applications over power consumption measurements.

4.2 CPU and Memory Workload Power Consumption

Within this test case we ran the same ramspeed workload with different parameters on both Ubuntu and L4 Linux systems. The first test was executed to see the influence of L4 microkernel on power consumption and memory transfer rates, therefore we ran the same workload in the same conditions on both Ubuntu and L4 systems. The power consumption measurements are shown in Fig. 2. It can be observed that power consumption of L4 microkernel during the workload phase is lower than the same phase of the test running on Ubuntu. Instead the reported performance of the benchmark for L4 is lower than the one reported for Ubuntu due to the microkernel implementation. In order to estimate energy efficiency for this workload when running on different systems we correlated the energy spent to finish the workload and the performance of the workload on host system. The obtained results are presented in Table 2.

Table 2. CPU and memory energy efficiency results

System (1)	**Ubuntu**	**L4 Linux**	
Execution time [s]	234	307	+31.19 %
Transfer rate [MB/s]	2936.47	2238.18	-23.78 %
Energy [J]	27300.60	34624.00	+26.82 %
System (2)			
Execution time [s]	246	314	+27.64 %
Transfer rate [MB/s]	2705.69	2158.31	-20.22 %
Energy [J]	11143.10	13849.60	+24.29 %

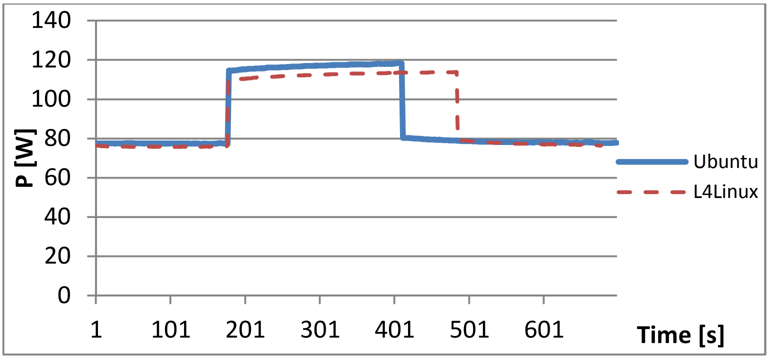

Fig. 2. CPU and memory power consumption profile

Power consumption of the system increases when running in the workload phase because the temperatures of the CPU cores increase with the execution time. In order to see how power consumption increases with workload execution time we run the same test with different number of counting times: ramspeed x 2 means double the size of workload and ramspeed x 4 specify that the workload is four times the normal ramspeed size (Fig. 3). When increasing the size of workload size the power consumption increases with almost 4 W from 112.5 W to 116.4 W on test system (2).

The current test was further extended in order to study the effect of parallelization of workload on available CPU cores. We ran two instances of ramspeed (2 x ramspeed) and four instances of the same workload (4 x ramspeed) (Fig. 3). It can be observed improvement in both performance and energy efficiency when executing multiple workload instances instead of one single instance. The obtained measurements are shown in Table 3.

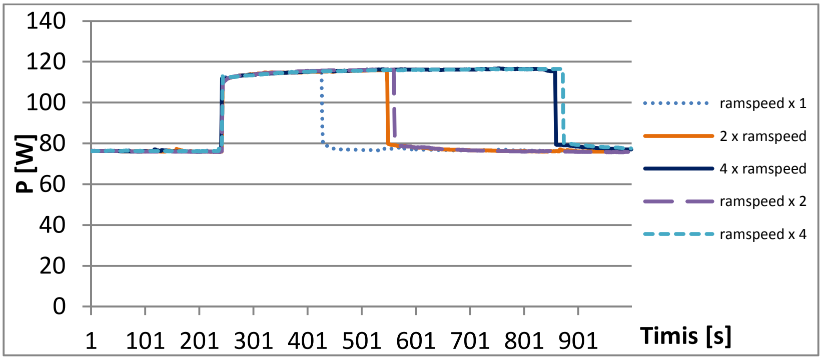

Fig. 3. Multi-tasking workload power consumption profile

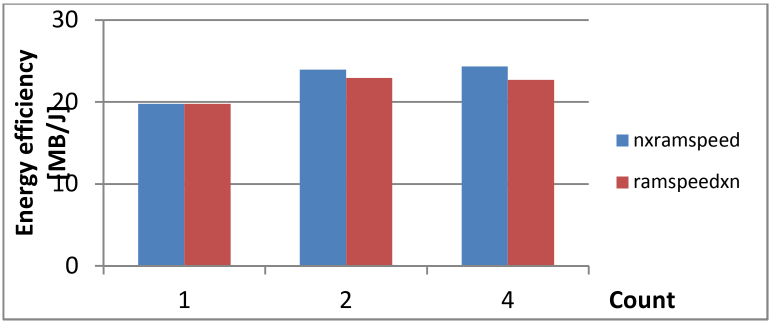

Fig. 4. Multi-tasking workload energy efficiency

Table 3. CPU and memory energy efficiency results

System (1)	2 x ramspeed	ramspeed x 2	4 x ramspeed	ramspeed x 4
Execution time [s]	306	319	618	631
Transfer rate [MB/s]	2742.03	2631.81	2807.65	2621.20
Energy [J]	35056.30	36623.60	71327.10	72818.80

In Fig. 4 energy efficiency of L4Linux ramspeed execution is shown when increasing the size of the workload. The workload is increased sequentially (called generic ramspeed x n) and parallel using multiple workload tasks (n x ramspeed). It can be observed that energy efficiency of the ramspeed workload increase when the workload size increase and when using parallelization compared with sequential execution.

4.3 IO HDD Workload Power Consumption

Power consumption of IO operations were performed using iozone hard disk benchmark. IOzone is a file system benchmark tool running on different platforms that generates and measures a variety of file operations: read, write, re-read, re-write, read backwards, read strided, fread, fwrite, random read. We executed the IO workload with different parameters on both operating systems under tests. Power measurements for one test execution are shown in Fig. 5. In our tests results we could not highlight significant differences between both performance and power consumption of IO operations with hard disk.

Table 4. Disk I/O energy efficiency results

System (1)	**Ubuntu**	**L4 Linux**	
Execution time [s]	130	131	+0.76 %
Transfer rate [ops/s]	15012	14795	-1.45 %
Energy [J]	10845.5	10777.6	-0.63 %
System (2)			
Execution time [s]	143	145	+1.40 %
Transfer rate [ops/s]	13636	13379	-1.88 %
Energy [J]	4320.72	4145.23	-0.41 %

The tests were executed using existing files of 1 GB and we used read and write operations using 1KB blocks of data. Power profiles of disk I/O test execution are presented in Fig. 5 and the same profile is obtained for both Ubuntu and L4Linux solutions. The energy efficiency is also similar on both platforms.

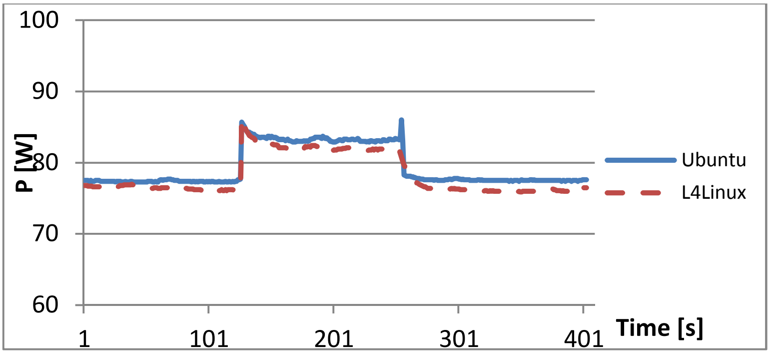

Fig. 5. Disk I/O workload power consumption profile

Table 5. Disk I/O energy efficiency results

System (1)	**Ubuntu XWin**	**Ubuntu Console**		**L4 Linux Console**	
AVERAGE	96.87 W	81.02 W	16.36 %	80.50 W	0.63 %
MINIMUM	95.50 W	78.80 W	17.49 %	79.10 W	-0.38 %
System (2)					
AVERAGE	36.23 W	32.02 W	11.62 %	31.12 W	-2.81 %
MINIMUM	34.50 W	31.20 W	9.56 %	30.50 W	-2.24 %

4.4 User Application Power Consumption

In order to see the power signature of real user applications running in L4 Linux we selected two applications: gzip and mplayer. We executed both applications on Ubuntu OS and L4 Linux. gzip application was used to compress and decompress a large file and its execution power consumption measurements are presented in Fig. 6. There are not important differences between file compression running on Ubuntu and L4 Linux.

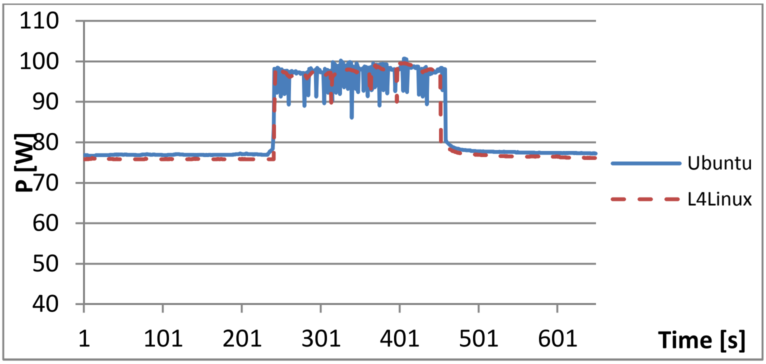

Fig. 6. Gzip compression power consumption

The last test was to run an AVI file with mplayer on three conditions: Ubuntu with X Windows system started, Ubunt without X Windows and L4 Linux without X Windows. The test results shown in Fig. 7 presents the power consumption of decoding process executed on Ubuntu and L4 Linux (Table 5).

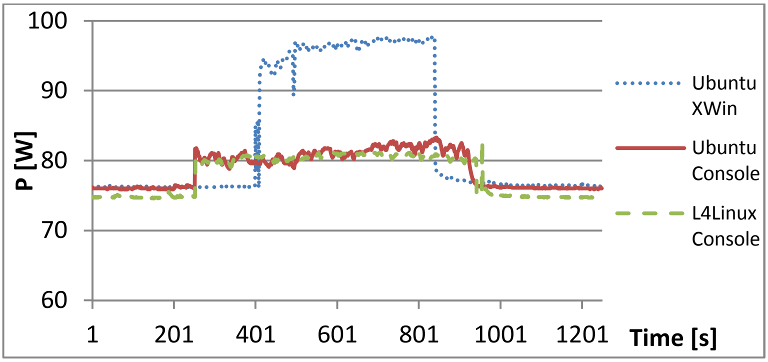

Fig. 7. Mplayer power consumption

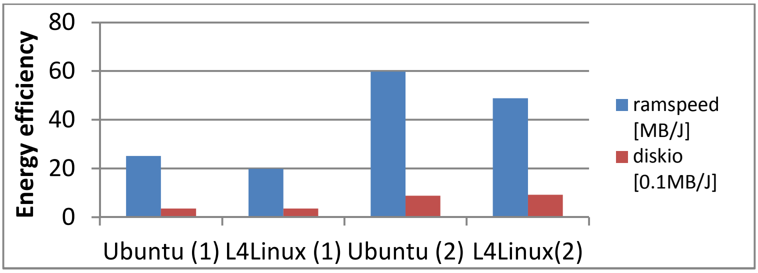

Fig. 8. Memory and I/O operations energy efficiency

5 Conclusions

This paper explores how virtualization influences the power consumption of both physical systems and virtual systems and which is the most efficient way to implement such applications. We proposed a number of test cases that can be used to evaluate power consumption and energy efficiency of virtualization systems. We run the tests on different common desktop and laptop multi-core systems.

In Fig. 9 the concluding results of energy efficiency of CPU, memory and disk I/O tests are shown. Due to the implementation particularities of L4Linux memory operations are less preformat than non-virtualization implementation therefore the energy efficiency is lower with ~25%. The disk I/O operations however are similar on both platforms Ubuntu and L4Linux. Another observation is that L4Linux implementation consumes less power than Ubuntu, when idle, on the same machine.

Acknowledgments. This work was supported by CNCSIS-UEFISCSU, project number PNII-IDEI 1009/2008. This work has been carried out in the context of the eMuCo project (www.emuco.eu), European project supported by the EU under the Seventh Framework Program (FP7) for research and technological development.

References

1. Carpenter, R.E.: Comparing Multi-Core Processors for Server Virtualization. White Paper, Intel Information Technology (2007), `http://www.multicoreinfo.com/research/papers/whitepapers/multicore_virtualization.pdf`
2. Dhiman, G., Marchetti, G., Rosing, T.: vGreen: A System for Energy Efficient Computing in Virtualized Environments. In: International Symposium on Low Power Electronics and Design, ISLPED 2009, USA (2009)
3. Clark, C., Fraser, K., Hand, S., Hansen, J.G., Jul, E., Limpach, C., Pratt, I., Warfield, A.: Live migration of virtual machines. In: Proceedings of the 2nd Conference on Symposium on Networked Systems Design & Implementation, NSDI 2005 (2005)
4. Tian, K., Yu, K., Nakajima, J., Wang, W.: How virtualization makes power management different. In: Proceedings of the Linux Symposium, OLS 2007, Canada (2007)

5. Chetan, S., Gautam Kumar, K., Dinesh, M.K., Abhimanyu, M.A.: Cloud Computing for Mobile World. Research Work (2010), `http://chetan.ueuo.com/projects/CCMW.pdf`
6. Nathuji, R., Schwan, K.: VirtualPower: Coordinated Power Management in Virtualized Enterprise Systems. ACM SIGOPS Operating Systems Review 41(6), SOSP 2007 (2007)
7. Verma, A., Ahuja, P., Neogi, P.: pMapper: Power and Migration Cost Aware Application Placement in Virtualized Systems. In: Proceedings of the 9th ACM/IFIP/USENIX International Conference on Middleware, Moddleware 2008, Leuven, Belgium (2008)
8. Ye, L., Lu, G., Kumar, S., Gniady, C., Hartman, J.H.: Energy-Efficient Storage in Virtual Machine Environments. In: Proceedings of the 6th ACM SIGPLAN International Conference on Virtual Execution Environments, VEE 2010, Pittsburgh, USA (2010)
9. Härtig, H., Roitzsch, M., Lackorzynski, A., Döbel, B., Böttcher, A.: L4-Virtualization and Beyond. Korean Information Science Society Review (December 2008)