Hypervisors Performance Evaluation with Help of HPC Challenge Benchmarks

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Abstract

Nowadays, more organizations are getting used to private and public clouds. So clouds must be robust enough to handle computing sensitive requests of users in a cost effective manner. Furthermore, it is intellectual to improve the cloud infrastructure performance by appropriate choices. In this paper we are going to evaluate various hypervisors performance, including VMware ESXi and Workstation, KVM, Xen, and Oracle VirtualBox using HPC Challenge (HPCC) benchmark suite and OpenMPI to find solutions for virtualization layer of cloud computing architecture.

Key words: cloud computing, cluster computing, virtualization, hypervisor, performance evaluation

1. Introduction

With the fast improvement of processing and storage technologies alongside the success of the internet, computing resources have become cheaper and more commonly available than ever before. These technological trends lead to a new computational model called cloud computing, in which resources like processors and storage spaces could be allocated to users or de-allocated from theme easily with help of virtualization technology through the internet in an on demand way [21]. A precise definition of cloud computing which we believe covers all major aspects of a cloud is given by The National Institute of Standards and Technology (NIST) [12]: “Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.” In General, cloud computing architecture composes of four layers [21]: hardware layer, infrastructure layer, platform layer, and application layer. Fig. 1 depict the layered model of cloud computing architecture. The hardware layer deals with physical aspects of the cloud which are implemented in datacenters. The platform layer consists of operating systems and application frameworks which provides APIs for web applications. The application layer consists of cloud applications.

The Infrastructure layer, also known as virtualization layer, creates a pool of storage computing resources by partitioning the physical resources using virtualization technologies (hypervisors) like VMware ESXi, Xen, and KVM. Virtualization layer actually is the heart of a cloud infrastructure, since many key features of cloud like dynamic resource allocation, which leads to tremendous cost savings, are only available through virtualization technologies. In this paper we are going to evaluate the performance of some commonly used and preferably open source virtualization technologies (hypervisors), including VMware
ESXi [2], KVM [6], Xen [1], Oracle VirtualBox [18], and VMware Workstation [17] with various measurements and metrics like processing power, memory updates capability and bandwidth, network bandwidth and latency using HPC Challenge (HPCC) [8] benchmark suite and Open MPI [5]. There are however, numerous other virtualization technologies also available, including Microsoft Hyper-V [16], OpenVZ [10] and Oracle VM [13].

There have been previous works in this area, only to mention a few: Younge et al. [20] analyzed the performance of Xen, KVM and VirtualBox using HPC Challenge benchmark, and they have suggested KVM as a preferable hypervisor. Luszczek et al. [9] evaluated the performance of HPC Challenge benchmark in several virtual environments, including VMware, KVM and VirtualBox with purpose of evaluating the overheads of the different aspects of the system affected by virtualization.

The rest of this paper is organized as follows. Section 2 discusses hypervisors we have used. In section 3 we describe the method we have used to evaluate the performance of virtualized clusters. Section 4 illustrates the results and discusses them. Finally the paper concludes in section 5.

2. Virtualization and Hypervisors

Virtualization refers to the technique or approach of running many smaller virtual machines (VMs) on a computer, each having their own operating system and configuration. A hypervisor, or virtual machine monitor (VMM) is a program that runs on a host machine and creates VMs and allocates resources such as processor and memory to them. Hypervisor abstracts VMs from each other. In cloud computing architecture, allocating or de-allocating resources dynamically to users is only available with help of virtualization technologies.

Hypervisors are divided into two categories:

1. *Bare-metal (type 1)* in which virtual machines directly run on host machine’s hardware. KVM, Xen and VMware ESXi are examples of open source or free implementation of this type.

2. *Hosted (type 2)* in which virtual machines run on host’s operating system. Oracle VirtualBox and VMware Workstation are examples of open source and commercial implementation of this type.

Fig. 2 shows a general scheme of bare-metal and hosted hypervisor.

In the following we are going to present a brief definition of each bare-metal and hosted hypervisor which have been used in our experiments.
Fig. 2: While bare-metal hypervisor runs directly on machine’s hardware (left), hosted hypervisor runs on host’s operating system (right)

The Kernel-based Virtual Machine, or KVM, is a Linux subsystem which leverages virtualization extensions to add a virtual machine monitor (or hypervisor) capability to Linux [6].

Xen is a virtual machine monitor which allows multiple commodity operating systems to share conventional hardware in a safe and resource managed fashion, but without sacrificing either performance or functionality. This is achieved by providing an idealized virtual machine abstraction [1].

VMware ESXi is the next-generation hypervisor, providing a new foundation for virtual infrastructure. ESXi operates independently from any general-purpose operating system, offering improved security, increased reliability, and simplified management. The compact architecture is designed for integration directly into virtualization-optimized server hardware, enabling rapid installation, configuration, and deployment [2].

Oracle VirtualBox is a cross-platform virtualization application. For one thing, it installs on existing Intel or AMD-based computers, whether they are running Windows, Mac, Linux or Solaris operating systems. Secondly, it extends the capabilities of existing computer so that it can run multiple operating systems (inside multiple virtual machines) at the same time [18].

VMware Workstation functions as a computer within a computer (hosted), so that you can startup an entire operating system and run any programs for that operating system with it, while keeping your original operating system environment intact (and usable) [17].

3. Performance Evaluation

In this section we evaluate the performance of virtualized environments created with either VMware ESXi 5, KVM 1.0, Xen 4.1 or as bare metal hypervisors and Oracle VirtualBox 4.2 and VMware Workstation 9 as hosted hypervisors for comparison. We use The HPC Challenge benchmark (HPCC) [8] scientific computing benchmark suite. The HPC Challenge benchmark consists of basically 7 tests. The characteristics of used benchmarks are summarized in Table 1.

We perform our experiments on homogenous virtualized environments build from Ubuntu Server 12.04 LTS image for single and two instance(s). Each instance has 2 CPU cores and 1 GB of RAM. Our host operating system is Ubuntu Desktop 12.04 LTS when it is needed. Host machine has Intel Core i7 processor with 8 GB of RAM. We benefit from OpenMPI-1.6.4 [5] which is an open source MPI-2 implementation for parallel experiments. The benchmarks were compiled using GNU C/C++ 4.1.
Performance results of HPL benchmark depend on two factors: the Basic Linear Algebra Subprograms (BLAS) [3] library, and the problem size. We use ATLAS [19] library in our experiments. The ATLAS (Automatically Tuned Linear Algebra Software) project is an ongoing research effort focusing on applying empirical techniques in order to provide portable performance. For problem size we get benefit of the following recommended equation:

\[ N = \sqrt{TM \div 8} \times 0.85 \]  

Which \( N \) is the problem size and \( TM \) is the total memory, including all nodes, in Byte. It reserves 15% of memory for operating system, which seems sufficient for Ubuntu Server 12.04 LTS.

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Target</th>
<th>Unit</th>
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<tbody>
<tr>
<td>HPL [14]</td>
<td>CPU performance</td>
<td>GFLOPS</td>
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<tr>
<td>DGEMM [4]</td>
<td>CPU performance</td>
<td>GFLOPS</td>
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<tr>
<td>PTRANS [15]</td>
<td>CPUs communication</td>
<td>GB/s</td>
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<tr>
<td>FFT [15]</td>
<td>CPU performance</td>
<td>GFLOPS</td>
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<tr>
<td>Effective Bandwidth (b_eff) (bw., lat.) [7]</td>
<td>Communication</td>
<td>GB/s, μs</td>
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</table>

Table 1. Benchmarks used for virtualized environment performance evaluation. B, FLOP, U and PS stand for bytes, floating point operations, updates, and per second, respectively.

4. Results

Each experiment executed 10 times so in total we had 150 executions executions (5 hypervisors × 3 types of cluster × 10 times). Here the results of 105 experiments (5 hypervisors × 3 types of cluster × 7 benchmarks) are going to present.

Fig. 3 shows the HPL results. In general VMware ESXi with cluster of two nodes had the best results with 29.94 GFLOPS, on the other hand, Xen with 8.14 GFLOPS could reach only 27.93% of ESXi. Having two VMs for ESXi, KVM and Oracle VirtualBox had better results for them.

![Fig. 3: Comparison of HPL benchmark](image-url)
Comparison of PTRANS benchmark is depicted in Fig. 4. Obviously adding more VMs decrease the gained bandwidth from two simultaneously working processors. So, having one VM will always reach the best result. VMware ESXi reached the highest with 1.78 GB/s. However other hypervisors also obtained near results to VMware ESXi in single instance case.

![Fig. 4: Comparison of PTRANS benchmark](image)

Fig. 5 illustrates RandomAccess benchmark results. VMware ESXi with single VM reached the highest memory updates ratio with 16.55 MUPS. Oracle VirtualBox did not perform well enough. It could reach only 0.41 MUPS in one VM case, which is only 2.47% of ESXi.

![Fig. 5: Comparison of RandomAccess benchmark](image)

As shown in Fig. 6, VMware ESXi, KVM, Oracle VirtualBox and VMware Workstation all having close results for one VM at a time for FFT benchmark. They have all obtained FFT performance between 2 and 2.3 GFLOPS for single instance with little variations.

For STREAM benchmark which is shown in Fig. 7 we obtained nearly same results for all hypervisors around 7 GB/s.

About DGEMM benchmark, as depicted in Fig. 8 both VMware ESXi and Workstation reached the highest performance with 15.6 and 15.11 GFLOPS respectively when there is one
VM. As it can be seen, adding more VMs decreased the DGEMM performance for all hypervisors.

Network bandwidth, as depicted in Fig. 9, evaluated using Effective Bandwidth (b_eff) benchmark. KVM and Xen shown better bandwidth performance than others with 0.35 and 0.29 GB/s in order, while ESXi could only reach 0.09 GB/s, which is only 25.71% of KVM. Note that running Effective Bandwidth (b_eff) benchmark on a single machine represents memory bandwidth and latency.

![Fig. 6: Comparison of FFT benchmark](image)

![Fig. 7: Comparison of STREAM benchmark](image)
5. Conclusions
Nowadays, more organizations are getting used to private and public clouds. So clouds must be robust enough to handle computing sensitive requests of users in a cost effective manner. Furthermore, it is intellectual to improve the cloud infrastructure performance by appropriate choices. As we mentioned before, cloud computing layered architecture consist of virtualization layer (also called infrastructure layer). In this paper we compared some commonly used and preferably open source virtualization technologies, including VMware ESXi, KVM, Xen, Oracle VirtualBox, and VMware Workstation with various measurements and metrics like processing power, memory updates capability and bandwidth, and network bandwidth using HPC Challenge (HPCC) benchmark suite and Open MPI. Afterwards, we specified the best solution from the average of 10 times execution for each one. As we concluded in previous section, in general, VMware ESXi obtained the best results, thus it can be a reliable solution for cloud or cluster infrastructure. However, when the workload is network bounded, KVM or Xen would be the preferable choice. Yet we need to investigate the results for CPU and memory bounded workloads as further studies.

References


