Research and Performance Evaluation of Open Source and Commercial Virtualization Hypervisors

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Abstract- *Virtualization has rapidly accomplished mainstream position in enterprise IT by providing transformative cost savings as well as improved operational efficiency, flexibility and IT service levels. While a full virtual infrastructure is composed of a wide collection of technologies that provide resource aggregation, availability, mobility and management, the foundational core of virtual infrastructure is the hypervisor. Hypervisor and virtualization technology helps to drive cloud computing, clustering, server consolidation, and high availability solutions. Virtualization, over the use of hypervisors, has become widely available and well understood by several people. Yet, there are a large range of different hypervisors, each having their own advantages and disadvantages. This paper delivers a quantitative and qualitative comparison of different virtualization hypervisors available for virtualization VMware ESX, Microsoft Hyper-V, open-source Xen and KVM, to authenticate their readiness for virtualization. The discussion in this paper should help IT decision makers, research personal and end users to choose the right virtualization hypervisor for their nature of work.*

Keywords- Virtualization, Hypervisor, Data centers, Virtual machines, Xen, KVM, Hyper-V

I. INTRODUCTION

Virtualization is the method of breaking up one or more physical servers into multiple virtual servers (or virtual machines) [1]. These virtual servers “reflect” and “act” like physical servers and can be transformed to more efficiently allocate the available resources or the organization’s data center. Numerous virtual servers can exist on a single physical server, sharing resources as required. The benefits of virtualization are presented in the fact that several software applications cannot exist on the same server using traditional server architecture, which leads to thousands of bucks of underutilized hardware resources. Virtualization is accomplished by addition of a piece of software to the server that turns into an abstraction layer between the physical servers and the virtual servers. This abstraction layer is identified as a hypervisor. Figure 1.1 demonstrates how a traditional server configuration looks like and how it is adjusted to create a new virtual infrastructure using a VMware hypervisor. supported host hardware, supported guest/host operating systems, hypervisor type, licensing method of the software, etc. Guest is capable of running its own operating

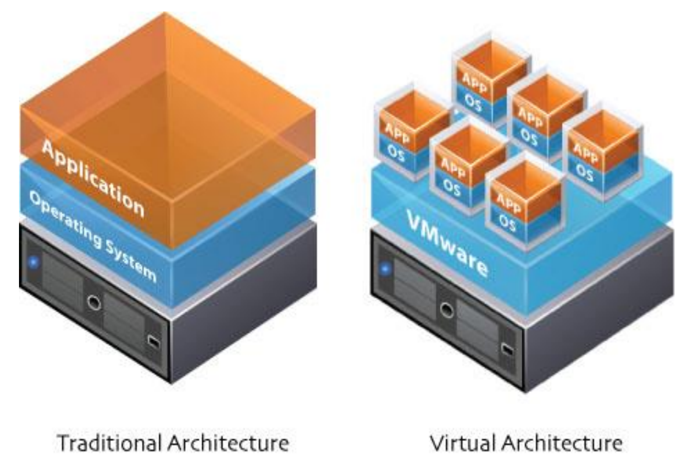

Fig. 1 Traditional vs Virtual Infrastructure

system, to which it looks like the virtual machine has its own RAM and CPU, i.e. it appears as if it has its own physical machine even though it does not. To do this efficiently, it requires support from the fundamental processor (a feature called AMD-V on AMD and VT-x on Intel). One of the significant functions a hypervisor provides is isolation, implication that a guest cannot affect the operation of the host or any other guest, even if it crashes. As such, the hypervisor must cautiously emulate the hardware of a physical machine, and except under carefully controlled situations, avoid access by a guest to the real hardware. How the hypervisor does this is a key element of virtual machine performance. In this paper we discuss the different factors that need to be considered while choosing virtualization solution, overview of hypervisors existing present-day, a relative and comparative study of open source and commercial hypervisors like Xen, KVM, VMware ESX, Hyper-v etc.,

II. FACTORS TO BE CONSIDERED WHILE CHOOSING VIRTUALIZATION SOLUTION

A. Architecture of hardware

This refers to the server architecture with which the virtualization software is compatible. This is one of the most significant elements to be considered as the software must be appropriate to the architecture of the platform in order to work properly. In addition to inspecting the compatibility of the software, it is desirable to check the hardware compatibility lists delivered by most virtualization solution packages.

B. Virtualization type

There are numerous methods of virtualizing servers, each of which uses a dissimilar configuration of hypervisors, operating systems, and applications. The different alternatives in terms of the types of Server Virtualization are Full Virtualization, Para virtualization, and OS Virtualization, which can be either with Hardware Assistance or without Hardware Assistance [Adams L et al, VMWare 2007].

1) Full Virtualization

This selection allows operating systems to exist on a single server within their own virtual machine. VMware ESX/ESXi is an example of a hypervisor that uses this virtualization preference.

2) Para-virtualization

Para virtualization happens when each guest operating system is allowed to identify that it has undergone virtualization. The result of this technique is reduced time consumed by the operating system performing functions that are more difficult to do when virtualized. Vware ESX/EXSi, Citrix XenServer, and Oracle VM Server are all hypervisors that can accomplish this method.

3) Hardware-Assisted Virtualization

Hardware assisted virtualization consumes the capabilities of the host’s hardware and processing power. This selection makes it possible to utilize certain features of high performance CPUs and permit guest operating systems to work independently. Microsoft Hyper-V, VMware ESX/ESXi, and Citrix XenServer are hypervisors that support this type of virtualization organization.

4) OS Virtualization

OS virtualization is a method that uses a single OS on a host server. Within this structure there occur certain spaces known as ‘containers’, each with their own set of resources. This is regularly present in hosting environments where customers might purchase servers and when resources are distributed to a large number of servers. Parallels Virtuozzo and Solaris Containers are examples of software that offer OS virtualization.

C. Supported guest/host operating systems

The operating systems that are compatible with the hypervisor or virtualization software are called as Guest operating systems. Guest operating systems are those inside the virtual machines within the virtual environment. If we have applications to run on virtual machines that can only run on specific operating systems, this spec is fundamental to our decision.

III. HYPERVISOR TYPES

This section defines whether the hypervisor runs directly on the host operating system called type1/bare-metal hypervisor or on a host operating system on the server, type 2/hosted

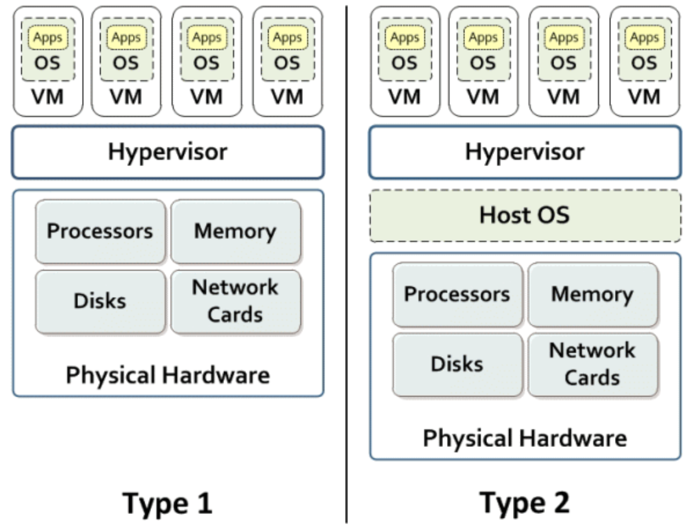

Fig. 2 Type 1 and Type 2 Hypervisors

hypervisor. Former hypervisors are installed and run directly on the host server. This acts as an intermediary level between the host server and the consequent operating systems on the virtual machines [1]. As a general rule, type 1/ bare-metal hypervisors offer a higher level of performance as they are installed straight on the main server hardware. They also have the competence to support a larger number of processors or virtual machines. Examples of type 1 hypervisors include VMware, ESXi, Citrix, XenServer, and Microsoft Hyper-V. The type 2 or hosted hypervisor is installed on an operating system on a host server. These hypervisors are installed similar to applications and allow virtual machines access to its hardware and resources. Oracle VirtualBox and VMware Server are examples of type 2 hypervisors. Fig. 2 shows the hypervisor types namely, type 1 and type 2.

IV. OVERVIEW OF HYPERVISORS

In this section we provide an overview of hypervisors available and its features. VMware vSphere Essentials provides the industry-leading virtualization platform for small businesses at a reasonable price. Small businesses can virtualize their physical servers and centrally manage these servers, reducing hardware costs and thus increase operating efficiency with a low upfront investment. VirtualBox is a powerful x86 and AMD64/Intel64 virtualization merchandise for enterprise as well as home-based use. VirtualBox an exceptionally feature rich, high performance product for enterprise customers, it is also the only professional solution that is freely accessible as Open Source Software. Microsoft Hyper-V Server 2008 R2 SP1 is a standalone product that delivers a reliable and optimized virtualization solution facilitating organizations to improve server utilization and reduce costs [14-15]. With the adding of new features such as live migration and expanded processor and memory support for host systems, it permits organizations to combine workloads onto a single physical server and is a worthy solution for organizations that consolidate servers as well as for development and test environments. XenServer provides the best-in-class performance for application and desktop virtualization with an incorporated virtualization platform for Citrix XenApp and XenDesktop. IBM offers PowerVM Standard Edition which provides the most complete virtualization functionality for IBM and Linux operating systems in the industry. KVM (Kernel-based Virtual Machine) is a full virtualization key for Linux on x86 hardware containing virtualization extensions (Intel VT or AMD-V) []. With Xen virtualization, a thin software layer known as the Xen hypervisor is implanted between the server's hardware and the operating system. This offers an abstraction layer that allows each physical server to run one or more "virtual servers", efficiently decoupling the operating system and its applications from the primary physical server. Oracle VM Server for x86 is a free server virtualization and management key that creates enterprise applications easier to install, manage, and support. Oracle VM simplifies the deployment and operation of your enterprise applications on a fully certified platform to reduce

Name	License	Anticipated User	VMs per Host	RAM per VM (in GB)	Hypervisor Type	Virtualization Type
VMware vSphere Essentials	Proprietary	Enterprise	512	32	Bare metal	• Full Virtualization • Hardware Assisted Virtualization • OS virtualization
Oracle VirtualBox	Open Source	• Enterprise • Small-Medium Business	128	1024	Hosted	• Hardware Assisted Virtualization • Para virtualization
Microsoft Hyper-V Server 2008 Enterprise	Proprietary	• Enterprise • Small-Medium Business	384	64	Bare metal	• Full Virtualization • Hardware Assisted Virtualization
Citrix XenServer	Proprietary	• Enterprise • Small-Medium Business • Personal	75	128	Bare metal	• Hardware Assisted Virtualization • OS virtualization • Para virtualization
IBM PowerVM Standard Edition	Proprietary	• Enterprise • Small-Medium Business	1000	4096	Hosted	Full Virtualization
KVM	Open Source	• Small-Medium Business • Personal		1	Hosted	• Full Virtualization • Hardware Assisted Virtualization • Paravirtualization
Xen	Open Source	Enterprise	500	1000	Bare metal	• Hardware Assisted Virtualization • Paravirtualization
Oracle VM Server for x86	Open Source	Enterprise	128	2	Hosted	• Hardware Assisted Virtualization • Paravirtualization

operations and support costs while concurrently increasing IT efficiency and agility [2]. A comparison chart representing different hypervisors has been given in the figure 2. Predicted users, licensing type of the software, the number of virtual machines supported per host, RAM support by VMs, type of hypervisor and virtualization technology it supports are given in the tabulation (see fig. 3).

V. CHOOSING THE RIGHT HYPERVISOR

One of the best ways to verify which hypervisor meets our needs is to compare their performance metrics. These include CPU overhead, amount of maximum host and guest memory, and support for virtual processors. But metrics alone should not determine the choice. In addition to the capabilities of the hypervisor, the guest operating systems that each hypervisor supports must be verified. If we are running heterogeneous systems in our service network, then we must select the hypervisor that has support for the operating systems currently run. If we run a homogeneous network based on Windows or Linux, then support for a smaller number of guest operating systems might fit our needs. All hypervisors are not made equal, but they all offer related features. Understanding the features they have as well as the guest operating systems each supports is a necessary phase of any hardware virtualization hypervisor selection process. Matching this data to the organization's requirements will be at the core of the decision. The following factors should be observed before deciding a suitable hypervisor.

1) Virtual machine performance

Virtual systems should meet or surpass the performance of their physical counterparts, at least in relation to the applications within each server. Everything ahead of meeting this benchmark is profit. Preferably, each hypervisor should optimize resources on the fly to maximize performance for each virtual machine. The matter is how much can be paid for this optimization. The size or mission-criticality of the project usually determines the value of this optimization.

2) Memory management

Support for hardware-assisted memory virtualization can be looked after. Memory over commit and large page table support in the VM guest and hypervisor are preferred features; memory page sharing is an optional extra feature you might want to consider.

3) High availability

Each major vendor has its own high availability solution and the way each achieves it may be wildly dissimilar, ranging from very complex to minimalist approaches. Considering both the disaster prevention and disaster recovery methods for each system is critical. It is not advisable to bring any virtual machine online without fully knowing the protection and recovery mechanisms in place.

4) Live migration

Live migration is extremely important for users; along with support for live migration across different platforms and the capability to simultaneously live migrate two or more VMs, you need to carefully consider what the individual hypervisor offers in this area.

5) Networking, storage, and security

In networking, hypervisors should support network interface cards (NICs) teaming and load balancing, Unicast isolation, and support for the standard (802.1Q) virtual local area network (VLAN) trunking. Each hypervisor should also support iSCSI- and Fibre Channel-networked storage and enterprise data protection software support with some preferences for tools and APIs, Fibre Channel over Ethernet (FCoE), and virtual disk multi-hypervisor compatibility.

VI. RELATED STUDY

There are numerous performance studies on virtualization, comprising [5], [9-11]. The virtualization overhead involves performances depreciation reasonably to native performances. Research has been carried out to measure the overhead of the virtualization for numerous hypervisor such as KVM, XEN [5], [7], [9], [11] and VMware ESX [6-7].

An overview of the Hardware supported Virtual Machines (HVM) implementation in Xen when compared to native performance is provided in [3]. It was divided into four parts namely, MMU virtualization, Basic Input Output System (BIOS) emulation, processor virtualization and I/O virtualization. The assessment was supported on a VT-x supporting Intel Core 2 Duo E6300 1.86 GHz processor with 2 GB of memory and a 100 Mbit network interface. Each virtual machine was allocated one virtual processor, 1 GB of memory and 10 GB of disk space. Results indicated that hardware supported virtualization is capable of reaching close to native performance on some of the examined workloads, but also find certain overheads on the remaining workloads. HVM has some overheads and are inherently caused by the underlying Xen architecture, especially due to emulated devices and shadow page tables. It has been found overheads of up to 90% loss in hardware virtual machines when compared to that of native performance.

A quantitative and qualitative comparison of two virtualization hypervisors existing for the x86 architectures namely, VMware ESX Server 3.0.1 and open-source Xen 3.0.3 to validate their readiness for enterprise datacenters is discussed [6]. The objective of this evaluation was to validate the performance and scalability of VMware ESX Server and Xen hypervisors. The tests were performed using a configuration with a single virtual CPU. A sequence of performance experiments was conducted for both hypervisors using Microsoft Windows as the guest operating system. The test workloads preferred for these experiments encompass several well-known standard benchmark tests such as SPECcpu2000 benchmark suite, Passmark, Netperf, SPECjbb2005 benchmark suite, etc., It has been identified that VMware ESX Server is far better prepared to meet the hassles of an enterprise datacenter than the Xen hypervisor.

In [11] they have used a toolkit called Xenoprof, a system-wide statistical profiling toolkit to analyse performance overheads experienced by networking applications running in Xen VMs. They have measured Xen's performance overheads for network I/O device virtualization in uniprocessor and multiprocessor systems. Real performance bugs encountered in Xen has been identified and resolved by the use of toolkit. Due to their study Xen came out with solutions to improve network performances of Xen virtualization. They have outlined that performance degradation is generally caused by a CPU utilisation which is more important within virtualization because virtualization increase the number of instructions that needs to be managed by the CPU.

The evaluation of various VMs for computationally intensive HPC applications using several standard benchmarks was discussed in [12]. The appropriateness of full virtualization, para virtualization, and OS-level virtualization in terms of network utilization, file system performance, SMP performance, and MPI scalability has been analysed for different systems like VMWare Server, Xen, and OpenVZ. Each system is benchmarked against a base x86 Fedora Core 5 install. All experiments were implemented on a cluster of 64 dedicated Dell PowerEdge SC1425 servers comprising of 2x3.2 GHz Intel Xeon processors, gigabit ethernet, 2 GB RAM, and an 80 GB 7200 RPM SATA hard disk. OpenVZ shows low overhead and high performance in both industry-standard scientific and file system performance benchmarks. Whereas Xen proved excellent network bandwidth and its exceptionally high latency hindered its scalability. VMWare Server demonstrated reasonable CPU-bound performance.

The performance analysis of two most popular open source hypervisors namely KVM and Xen is discussed in [17]. The benchmarking tools used by [17] are different from the tools that were used by [11]. They are using three different benchmark tools to measure the performances namely, Linpack, LMbench and IOzone. Their experiment is divided in three parts according to the specific utilisation of each tool. The results showed that the processing efficiency of Xen on floating point is better than KVM because Fedora 8 virtualized with Xen have performances which represent 97.28% of the native rather than Fedora 8 virtualized with KVM represent only 83.46% of the native performances. The memory virtualization of Xen and KVM is carried out and compared to native memory performances with LMbench. It has been observed that the memory bandwidth in reading and writing of Xen are certainly close to native performances. However the performances of KVM are slightly slower for reading but significantly slower concerning the writing performances. The native performances are compared to the virtualization performances of Xen and KVM using IOzone which is used to perform file system benchmark. Without Intel-VT processor the performances of either Xen or KVM are around 6 or 7 times slower than the native performances. However within the Intel-VT processor the performances of Xen increase considerably because the performances are even better than native performances. However KVM does not improve these performances.

A quantitative performance assessment of virtualization supported by Microsoft Hyper-V hypervisor is studied in [13-15]. In study made by [15], a chain of performance experiments were conducted on each virtualization hypervisor of the latest versions and Linux PREEMPT-RT as the guest operating system. Comparisons between the top three leading bare-metal hypervisor families which are Microsoft Hyper-V, VMware ESXi and Xen were presented. VMware ESXi leverage full virtualization whereas Xen and Hyper-V are micro kernalized that leverage both para and full virtualization. The para virtualization approach in Hyper-V performs better than its corresponding hardware assisted approach by a factor of two, while it is a factor of 1.5 for Xen. Research carried out by [15] found that Microsoft has achieved a very high level in almost all areas with its revised hypervisor Windows Server 2008 R2 Hyper-V. It has been identified that an existing server can usually be consolidated on a current system with Hyper-V without any loss in throughput, if the necessary number of logical cores for the guest operating system is supported by Hyper-V. The performance and ability of hypervisors to manage resources at high levels of utilization are tested with two hypervisors Microsoft Hyper-V and VMware vSphere 5, part of Windows Server 2008 R2 SP1 [14]. VMware vSphere 5 outperformed Microsoft Hyper-V R2 SP1 by 18.9 % when 30 virtual machines were run on each physical machine. VMware vSphere 5 also allocated server resources among individual VMs more equally than Microsoft Hyper-V R2 SP1 (39.2 % less variation), resulting in more consistent performance across all virtual machines. Results indicated that VMware vSphere 5 can deliver superior performance in a heavily virtualized environment over Microsoft Hyper-V R2 SP1.

VII. DISCUSSION

The objective of this evaluation was to validate the performance of VMware ESX Server, Hyper-V, KVM and Xen hypervisors. The assessment also highlighted several key issues that are significant for successful cloud or datacenter deployments. Moreover, the test plans for evaluating the scalability of different virtualization hypervisors by running several virtual machines concurrently. Consumers have recognized a number of operational characteristics that are essential to successful cloud deployments like performance, maturity of the hypervisor, scalability, support and maintainability, etc. It is difficult to convincingly present hypervisor performance measurements as there are multiple benchmarks existing which are not universal in the methodologies and metrics. But it is found that Xen hypervisor is fundamentally memory usage, lowering processing time and networking efficiency [16]. A critical advantage of the Xen hypervisor is its neutrality to the different operating systems. Due to its independence, Xen can allow any operating systems such as Linux, Solaris, BSD, etc. to be the Domain0 thereby confirming the widest possible use case for customers. We have found that VMware ESX Server is far better prepared to meet the demands of an enterprise data center or cloud deployments than the Xen or KVM hypervisors.

VIII. SERVER VIRTUALIZATION MARKET – GARTNER STUDY

Server virtualization includes the hypervisor, VM and virtual machine monitors (VMMs). The key to "virtualizing" a server is the hypervisor. A hypervisor is a layer of software that runs directly on hardware and allows the definition of fixed partitions with predefined priorities for accessing hardware resources. These partitions are incomplete VMs because they prioritize, but do not share, all hardware resources. To maintain flexible configuration, a hypervisor in common is implemented with a VMM. The VMM virtualizes all hardware needed for VMs to run. Most products presently labeled hypervisors package a VMM. According to Gartner inc. the global x86 server virtualization markets is projected to reach $5.6 billion in 2016, an increase of 5.7 percent from 2015. Regardless of the overall market increase, new software licenses have declined for the first time since this market became mainstream more than a decade ago. The market remains conquered by VMware, however, Microsoft has worked its way in as a mainstream competitor for enterprise use. There are also numerous niche players including Citrix, Oracle and Red Hat, in addition to an explosion of vendors. While server virtualization remains the most common infrastructure platform for x86 server OS workloads in on-premises data centers, Gartner analysts consider that the impact of new computing styles and approaches will be increasingly important for this market. This includes OS cloud computing and container-based virtualization. The trends are varying by organization size more than ever before. According to Gartner, practice of server virtualization among organizations with larger IT budgets remained constant during 2014 and 2015. It persists to be a significant and heavily used technology for these businesses, but this market segment is awaiting saturation. In distinction, organizations with smaller IT budgets anticipate a further decline in usage through to at least 2017. This is causing an overall decline in new expenditure for on-premises server virtualization. Gartner considers that organizations are rising their usage of "physicalization", choosing to run servers without virtualization software. More than 20 percent of these organizations expect to have less than one-third of their x86 server OSs virtualized by 2017 — twice the amount reported for 2015. However, the underlying motivation remains varied.

IX. CONCLUSION

The use of the virtualization technology has rapidly increased in past few years because of the benefits associated to it. Virtualization helps to reduce the hardware cost with performances which are improving persistently. Many researches are carried out in this domain to improve the performance. The primary goal of this manuscript is to evaluate the feasibility of virtualization hypervisors in HPC environment. We combine the feature comparison along with the performance results of existing works, and evaluate the potential impact on virtualization. Moreover, we believe these findings to be of great importance to other public and private cloud deployments, as system utilization, operating cost, quality of service and computational efficiency might be improved through the cautious evaluation of underlying hypervisors. A quantitative and qualitative comparison of different virtualization hypervisors VMware ESX, Microsoft Hyper-V, open-source Xen and KVM is considered to authenticate their readiness for virtualization. The Xen hypervisor is the most used virtualization platform in the cloud computing space. Xen hypervisor supports both para virtualized and fully virtualized guests and hence Xen consumers can take advantage of both the latest in hardware and software virtualization technology. By functioning closely with hardware companies comprising networking equipment vendors, the Xen hypervisor turn out to be the testing ground for new hardware ensuring that Xen is always a cutting edge solution.

REFERENCES

[1] VMware, Inc. White paper: Virtualization overview. (2006)

[2] Oracle, Inc. White peper: Oracle VM – Concepts Guide for Release 3.3. (2015)

[3] Jacob Faber Kloster, Jesper and Kristensen Arne Mejlholm: A Comparison of Hardware Virtual Machines versus Native Performance in Xen. (2007)

[4] Adams K and Agesen O: A Comparison of Software and Hardware Techniques for x86 Virtualization. ASPLOS, (2006)

[5] Paul Barham, Boris Dragovic, Keir Fraser, Steven Hand, Tim Harris, Alex Ho, Rolf Neugebauer, Ian Pratt and Andrew Warfield: Xen and the Art of Virtualization. Proceedings of the Nineteenth ACM Symposium on Operating Systems Principles, (2003)

[6] VMware, Inc. white paper: A Performance Comparison of Hypervisors. http://www.vmware.com/pdf/hypervisor_performance.pdf , (2007)

[7] C. Waldspurger: Memory Resource Management in VMware ESX Server. Operating Systems Design and Implementation (OSDI), (2002)

[8] VMware, Inc. white paper: Understanding Full Virtualization, Paravirtualization, and Hardware Assist. (2007)

[9] P. Apparao, S. Makineni, and D. Newell: Characterization of Network Processing Overheads in Xen. IEEE International Workshop on Virtualization Technology in Distributed Computing (VTDC), (2006)

[10] L. Cherkasova and R. Gardner: Measuring CPU Overhead for I/O Processing in the Xen Virtual Machine Monitor. USENIX Annual Technical Conference, (2005)

[11] Menon, J.R. Santos, Y. Turner, G.J. Janakiraman, and W. Zwaenepoel: Diagnosing Performance Overheads in the Xen Virtual Machine Environment. ACM/USENIX International Conference on Virtual Execution Environments (VEE), (2005)

[12] J. P. Walters, Vipin Chaudhary, Minsuk Cha, Salvatore Guercio Jr. and Steve Gallo: A Comparison of Virtualization Technologies for HPC. International Conference on Advanced Information Networking and Applications, (2008)

[13] Fujitsu Technology Solutions, White paper: Performance Report Hyper-V. https://sp.ts.fujitsu.com/dmsp/Publications/public/wp-PR-Hyper-V-en.pdf, (2010)

[14] VMware, Inc.: Principled Technologies, Test report summary, Virtualization performance: VMware vSphere 5 vs. Microsoft Hyper-V R2 SP1. http://www.vmware.com/content/dam/digitalmarketing/vmware/en/pdf/products/vsphere/vmware-vsphere-vs-hyper-v.pdf, (2011)

[15] Hasan Fayyad-Kazan, Luc Perneel and Martin Timmerman: Benchmarking the Performance of Microsoft Hyper-V server, VMware ESXi and Xen Hypervisors.

Journal of Emerging Trends in Computing and Information Sciences, (2013)

[16] XenSource: A Performance Comparison of Commercial Hypervisors. http://www.xensource.com/Documents/hypervisor_performance_comparison_1_0_5_with_esx-data.pdf, (2007)

[17] C. Jianhua, H. Qinming, G. Qinghua and H.Dawei: Performance Measuring and Comparing of Virtual Machine Monitors. Embedded and Ubiquitous Computing, (2008)