Research Article

Empirical Analysis of Server Consolidation and Desktop Virtualization in Cloud Computing

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Physical server transitioned to virtual server infrastructure (VSI) and desktop device to virtual desktop infrastructure (VDI) have the crucial problems of server consolidation, virtualization performance, virtual machine density, total cost of ownership (TCO), and return on investments (ROI). Besides, how to appropriately choose hypervisor for the desired server/desktop virtualization is really challenging, because a trade-off between virtualization performance and cost is a hard decision to make in the cloud. This paper introduces five hypervisors to establish the virtual environment and then gives a careful assessment based on C/P ratio that is derived from composite index, consolidation ratio, virtual machine density, TCO, and ROI. As a result, even though ESX server obtains the highest ROI and lowest TCO in server virtualization and Hyper-V R2 gains the best performance of virtual machine management; both of them however cost too much. Instead the best choice is Proxmox Virtual Environment (Proxmox VE) because it not only saves the initial investment a lot to own a virtual server/desktop infrastructure, but also obtains the lowest C/P ratio.

1. Introduction

Well-known public large-size cloud and private enterprise-owned cloud are currently leading cloud computing and services, for example, Amazon AWS, Google App Engine, and Windows Azure in public cloud and Salesforce.com and EMC² in private cloud. In contrast, small-to-medium sized enterprises (SMEs), educational institutes, and social groups are also very eager to pursue the services they want based on virtual server in cloud (VSiC) [1] architecture due to cost reduction, performance escalation, and security improvement. With this service, the operational costs for the information system can be drastically reduced and it can quickly increase the competitiveness of its information system, which is sustained by the following advantages: centralized monitoring, quick management, dynamic optimization, and efficient backup.

Technically, unexpected situations with service-type servers, such as websites, databases, AP servers, and file servers, bring much trouble for enterprises. Once a service

stops its function, it can cause faulty data, stalled production lines, and interrupted operation procedures, leading to multiple losses. However, a physical host has problems of promptness of service transfer to another host, restarting the service, and inability to update data in real time. The hardware, information, and data will be obstacles for enterprises to overcome.

To solve the issues mentioned above, virtual machine management system or hypervisor [2], such as VMware ESX/ESXi Server, Microsoft Hyper-V R2 [3], and Proxmox virtual environment (Proxmox VE) [4], is able to deliver the virtual machine services for virtual server/desktop infrastructure with high availability in computing, secured networking, and consolidated storage. With this approach, users make it possible to adopt low cost thin clients (a low-end PC or PDA) to link to the system for the services [5], reducing IT purchasing cost and saving computation power because thin client devices are easier to setup where the chances of malfunction, heat crash, and computer virus are considerably

low. In addition, easy to use through wireless mobile computing environment gains peoples' attraction a lot.

As the virtualization architecture expands continuously, network storage services have become part of the virtualization architecture. Openfiler [6] is a storage management system used for disk read/write accessing in a shared storage among several virtual machines or servers in enterprises. It is a free and conducive system that supports both network-attached storage (NAS) [7] and storage area network (SAN) [7] functions. As installed, it can be managed via web browsers in conjunction with iSCSI shared storage (IPSAN) [7] technique to provide file accessing on cloud computing servers. One can also use logical unit number (LUN) [8] through iSCSI to complete the placement of block accessing for virtual machines that are created by VMware or Hyper-V. This paper will evaluate the performance of accessing to block storage area network with Openfiler.

The goal in this paper also wants to clarify a credibility of cost and benefits on infrastructure virtualization. Speaking of virtualization cost and benefits, we will give the exploration of total cost of ownership (TCO) and return on investment (ROI) individually in the following statements. ROI [9] related to two factors, savings and investment, is equal to savings/investment, where investment represents the sum of incremental investment in transition from physical to virtual (new servers, shared storage, software licenses & support, services and training, etc.). In addition to investment, TCO [10] yet includes IT administration and downtime cost. Apparently, ROI and TCO can be properly undertaken well according to how big infrastructure has been virtualized. In terms of virtualization, how many infrastructures can be virtualized that intuitively depend on the ratio of the virtual machines per core (VMs/core), the so-called consolidation ratio [11]. The consolidation ratio is a measurement unit that virtualization vendors use with extreme prudence to provide a rough idea of the server consolidation level that can be achieved on their hypervisors. Virtual infrastructure as we know has been classified into server virtualization and desktop virtualization. We will explore the consolidation ratio and TCO/ROI for both server and desktop virtualizations in this study.

In addition, how to appropriately choose the virtual machine management (i.e., hypervisor) for the desired server/desktop virtualization is a really tough problem of a trade-off between performance and cost before making the decision to deploy virtual server in cloud (VSiC) as a new IT. Given five hypervisors used to establish VSICs, this paper introduces a composite index to represent the evaluated functional performance as well as formulates a proper equation to stand for the estimated virtualization cost so that a C/P ration will conclude a careful assessment about a variety of VSICs discussed in this paper.

2. Structure of Virtual Machine and Shared Storage

The purpose of this session is to setup five different virtual servers in cloud (VSiC) and provide an appropriate assessment for every virtual machine monitor (i.e., hypervisor).

TABLE 1: Hypervisor architecture.

VMM	Hypervisor architecture
VMware ESXi 5.0 (Redhat Linux)	Bare-metal/monolithic
MS Hyper-V R2 (Windows Server 2008)	Bare-metal/microkernel
Proxmox VE* (Debian)	Hosted
KVM* (Ubuntu Enterprise Server)	Hosted
Xen* (Cent OS)	Bare-metal/microkernel

* Open source.

These assessments can provide an optimal solution for SMEs, schools, and social groups. This research will setup and implement five heterogeneous virtual machine management systems which are (a) vSphere ESX/ESXi, (b) Hyper-V R2, (c) Proxmox virtual environment, (d) Ubuntu KVM [12], and (e) CentOS Xen [13], where they are shown in Figures 1, 2, 3, 4, and 5, respectively. Moreover, five heterogeneous hypervisors all link to a shared storage Openfiler through LAN, which is a type of IPSAN storage as shown in Figure 6.

Noted that vSphere ESX/ESXi Server, Hyper-V Server 2008 R2, or CentOS-based Xen required at least a stand alone machine for installation, Ubuntu Enterprise Server has to at least include 2 physical machines (Cloud Controller and Node Controller) and Proxmox VE at least a master or optionally adding multiple nodes as well.

As shown in Table 1, hypervisor includes all kinds of virtual machine architectures and types, hence referred to as heterogeneous virtual server in cloud. Virtual machine architectures are divided into hosted architecture, such as (a) and (b), and bare-metal architecture, such as (c), (d), and (e); its types are classified into paravirtualization, such as (d) and (e), full-virtualization, such as (a), (b), and (c), and hardware-assisted virtualization for all of them. This is because the new x86 machines, regardless of 32-bit or 64-bit, now support Intel VT-x and AMD-V virtual instructions.

3. Formulation of Consolidation Ratio and TCO/ROI

The aim of this section is first to understand the consolidation ratio of VMware ESX server as well as TCO/ROI evaluated at VMware TCO/ROI calculator [14]. Consolidation ratio means the number of VMs running in a server concurrently depending on the number of workloads and the average number of VMs per core. The max consolidation ratio per VMware ESX server is by default calculated as 1.5 VMs per core multiplied by the total number of cores per server [15]. That is, it gives 12:1 in ESX's server favor. Based on Taneja Group observations early in 2009 [16] during testing as well as their familiarity with a broad range of virtual server infrastructures, they claimed there are many realistic workloads under which ESX4 gains a 2:1 VM density advantage comparing with Hyper-V R2 and XenServer 5.5. Thus, we extensively proposed to analyze VM density according to a VMware official document for EXS server [14] and a testing report from consulting services [16] such that the consolidation ratio for the other hypervisors can be obtained.

FIGURE 1: vSphere ESX/ESXi server.

On the other hand, the ROI required for the transition to virtual infrastructure evaluates the percent of total saving/total cost, where total saving consists of capital expenditure, operational expenditure, and downtime cost; total cost is composed of new servers, storage, network storages, software license & support, server, and training [14]. TCO is the costs associated with operation of datacenter which include capital expenditure (servers, storage, and switches), operational expenditure (power & cooling, infrastructure administration labors, and rack space), and business agility (planned downtime, unplanned downtime, and business downtime) [14]. Furthermore, the TCO/ROI for the other hypervisors has been estimated carefully according to VM density and the ratio of ESX normalized performance index to anyone.

4. Empirical Analysis Method

With respect to the performance evaluation for the virtual machine monitor, a variety of guest OS and two well-known

test tools are adopted in this study. PassMark PerformanceTest 7.0 (at http://www.passmark.com/download/pt_download.htm) is applied to the test of virtual machine performance for the Windows series guest OS like Windows XP, Windows 7, and Windows Server 2003, and UnixBench 5.1.3 (at <http://byte-unixbench.google-code.com/files/UnixBench5.1.3.tgz>) is employed for Linux series guest OS like Ubuntu. According to evaluated performance score for each virtual infrastructure server, we derived the respective scores into a composite index, each hypervisor on (1) and (2), and sequentially normalized to be a value ranging from 0 to 1 on (3), where we refer to this as a normalized composite index related to virtual machine performance. In (1), WS_i is a test score for various guest Windows OSs (e.g., Win XP, Win Server 2003, and Win 7) running in a VM, and accordingly, WS_{mean} represents a mean test score for various guest OSs; in (2), LS_{mean} stands for a mean test score for a guest Linux OS (e.g., Ubuntu and CentOS); in (3), CI_{vm} means a VM composite index for a specific hypervisor, and two coefficients λ_1 and λ_2 act as a

FIGURE 2: Hyper-V Server 2008 R2 server.

weighted average; in (4), $\overline{CI}_{vm_k}$ represents a normalized VM composite index for a specific hypervisor. Consider

$$WS_{mean} = \frac{\sum_{i=1}^N WS_i}{N}, \quad (1)$$

$$LS_{mean} = \frac{\sum_{j=1}^M LS_j}{M}, \quad (2)$$

$$CI_{vm} = \lambda_1 \cdot LS_{mean} + \lambda_2 \cdot WS_{mean} \quad (3)$$

s.t. $\lambda_1 + \lambda_2 = 1,$

$$\overline{CI}_{vm_k} = \frac{CI_{vm_k}}{CI_{vm_{ESX}}}. \quad (4)$$

In order to achieve virtual infrastructure together with a shared storage, we first have to establish a set of block storage area network system called Openfiler and then mount shared storage to each virtual server. After that, we go for the performance evaluation of accessing block storage by using Linux `hdparm` command [17] to test disk reading speed. Likewise, we do the same thing as the above mentioned procedure to develop a composite index on (5) and its normalized composite index on (6) associated with storage-accessing speed performance. Finally, we derive the composite index

for total on (7) and a normalized one on (8). In (5), CS_{mean} is a mean test score for cache read speed performance on a guest Linux OS in a VM, DS_{mean} a mean test score for disk read speed performance, and CI_{sa} a storage-accessing speed composite index; in (6), $\overline{CI}_{sa_k}$ stands for a normalized storage-accessing speed composite index for a certain hypervisor; in (7), CI represents a composite index for a certain hypervisor for overall, and in (8), $\overline{CI}$ represents a normalized composite index. In terms of average, three sets of coefficients indicated by ν_1/ν_2 , w_1/w_2 , and η_1/η_2 are designated to act as a weighted average for equation in (5), (7), and (8), respectively. Consider

$$CI_{sa} = \nu_1 \cdot CS_{mean} + \nu_2 \cdot DS_{mean} \quad (5)$$

s.t. $\nu_1 + \nu_2 = 1,$

$$\overline{CI}_{sa_k} = \frac{CI_{sa_k}}{CI_{sa_{ESX}}}, \quad (6)$$

$$CI = w_1 \cdot CI_{vm} + w_2 \cdot CI_{sa} \quad (7)$$

s.t. $w_1 + w_2 = 1,$

$$\overline{CI} = \eta_1 \cdot \overline{CI}_{vm} + \eta_2 \cdot \overline{CI}_{sa} \quad (8)$$

s. t. $\eta_1 + \eta_2 = 1.$

FIGURE 3: Proxmox virtual environment server.

In this paper, we mainly conduct a credibility of cost and benefits before and after infrastructure virtualization. Speaking of cost and benefit, we will explore the consolidation ratio and TCO/ROI of both server consolidation and desktop virtualizations as mentioned above. VMware ESX server is first chosen to evaluate its consolidation ratio and estimate TCO/ROI at VMware calculator webpage. The consolidation ratio and TCO/ROI of both server and desktop virtualizations for the other hypervisors will be proportional to both its VM density (major part) and the ratio of ESX normalized composite index to alternative one (minor part). We broke the costs about capital expenditure, operational expenditure, and business agility into 13 items. Technically the table as listed in Table 2 gives us an insight to realize which item highly concerned with the VM density and/or normalized performance index ratio, which are derived from TCO/ROI calculation. Moreover, a formula for calculating the expenditure of TCO/ROI has been derived on (9) where VMD_{ESX} represents VM density for ESX server and $VMD_{hypervisor}$ for the other hypervisors; $Cost_{ESX}$ stands for the expenditure for ESX server and $Cost_{hypervisor}$ for the other hypervisors. There is no the initial cost of software package for Proxmox VE,

Ubuntu KVM, and CentOS Xen due to open source software. However, the initial cost of ESX server software package (approximate US\$ 12,668) is greater than that of Hyper-V R2 (approximate US\$ 6,000). Consider

$$Cost_{hypervisor} = \left(\alpha \cdot \left(1 - \frac{VMD_{hypervisor}}{VMD_{ESX}} \right) + \beta \cdot \left(1 - \frac{CI_{hypervisor}}{CI_{ESX}} \right) \right) \cdot Cost_{ESX} + \text{initial cost} \quad (9)$$

$$\text{s.t. } 0 \leq \alpha \leq 1$$

$$0 \leq \beta \leq 1$$

$$\alpha + \beta = 1.$$

5. Experimental Results and Discussion

There are three experiments and the discussion presented in the following subsections.

FIGURE 4: Ubuntu KVM server.

5.1. Assessment of Virtual Machine Performance. The server hardware specification is listed in Table 3.

The resulting score is an average of various scores from test items, for example, CPU, memory, storage, network, and 2D graph. In the experiment, two testing softwares (PassMark PerformanceTest 7.0 and UnixBench 5.1.3) are applied to evaluate the virtual machine performance for hypervisors such as ESXi 5.0, Hyper-V R2, Proxmox VE, Ubuntu Enterprise Server KVM, and CentOS Xen. A summary of the virtual machine performances is shown in Table 4 as well as Figures 7 and 8.

Different guest OS is installed separately on each virtual machine and adds up to 5 VMs in each predetermined virtual machine monitor (one of the above-mentioned hypervisors). They are divided into Windows series and Linux series guest OSs. After that, the testing software will be taken to analyze a set of target items as mentioned above.

5.2. Performance Evaluation of VM Accessing Shared Storage. In the experiment, according to the same server hardware specification as mentioned above, Openfiler storage device is separately mounted onto five virtual servers in cloud to test disk-accessing speed. Tests carried out two disk-accessing

speed indicators, (a) timing cached reads (MB/sec) and (b) timing buffered disk reads (MB/sec) [18]. A summary of storage-accessing speed performances is shown in Table 5 as well as Figures 7 and 8.

5.3. Estimation of Consolidation Ratio and TCO/ROI. This part goes to the estimation of the consolidation ratio and TCO/ROI for each virtual server infrastructure as mentioned above. We choose VMware ESXi server as a benchmark and use VMware TCO/ROI calculator to yield its server/desktop consolidation ratio and TCO/ROI quantity. VMware ESX exceeds 2 times the workload capacity per server for the competitive hypervisors such as hypervisor-V R2, XenServer 5.5, and the others [16]. Accordingly, we assumed ESXi achieved 2:1 VM density per server advantage over the other hypervisors in this study. Thus, ESXi achieved the consolidation ratio 12:1 in server virtualization as well as 96:1 in desktop virtualization because of 1.5 VM per core; instead the other hypervisors result in 6:1 in server virtualization as well as 48:1 in desktop virtualization. We estimate that TCO/ROI for alternative hypervisor is greatly proportional to its VM density (i.e., major part of estimation) and additionally adds somewhat fluctuations or changes to the evaluation of TCO

FIGURE 5: CentOS Xen server.

FIGURE 6: Virtual server in cloud and a shared storage with Openfiler.

TABLE 2: Cost affected by VM density and performance composite index ratio.

Cost	VM density (workload counts)	Performance composite index ratio
Capital expenditure		
Client HW + MS VDA	✗	✗
Server HW	✓	✗
Storage HW	✗	✗
Networking and security HW	✓	✗
Hypervisor SW + SnS	✓	✗
Operational expenditure		
Infrastructure admin	✓	✓
Power and cooling	✓	✓
Rack space and office spaces	✓	✗
Services + Training	✗	✗
Business agility		
Planned downtime	✗	✗
Unplanned downtime	✗	✗
Business downtime	✓	✓
Other + Tax	✓	✗

FIGURE 7: Composite index distribution.

part based on the ratio of ESXi normalized composite index to alternative one (i.e., minor part of estimation). In the experiment, we have deployed up to 50, 100, 150, 200, 250, and 300 workloads for the transition to their respective server virtualization with a 5-year duration. A summary of TCO/ROI calculation for 5 years is shown in Figures 9 and 10 in server virtualization as well as Figures 11 and 12 in desktop virtualization.

5.4. Cost Estimation for Server/Desktop Virtualization. According to the cost formula on (9), this part gives the operation cost for server/desktop virtualization so that the ratio of cost to performance (C/P ratio) for various virtual machine managements (hypervisors) is able to carry out the goal of the assessment in this paper. With a basis cost

FIGURE 8: Normalized composite index distribution.

FIGURE 9: TCO histogram of server consolidation.

of vSphere ESX server indicated in (9), the operation cost computation to Hyper-V R2, Proxmox virtual environment, Ubuntu KVM, and CentOS Xen are conducted to disclose the real assessment of virtual server/desktop infrastructure. In terms of VM performance as indicted in (7) and (8), the composite index presents how the function of VM and its related storage-accessing speed perform in the various hypervisors, and the results are shown in Figures 7 and 8 as well. As we can see in Figure 13, a $\text{Cost}_{\text{hypervisor}}$ divides $\overline{\text{CI}}$ and yields the C/P ratio with varying coefficients α/β , and the summary is also listed in Table 6. Even though Hyper-V R2 gains the best performance, Proxmox VE obtains the best choice in this study due to the lowest C/P ratio.

5.5. Discussion. In terms of VM performance and its storage-accessing speed as shown in Figures 7 and 8, Hyper-V R2 gains the best performance overall because of the highest composite index. As shown in Figures 9 and 10 in the server virtualization, the best choice is to take 150 workloads with ESX server because this combination will achieve the highest ROI and the lowest TCO over the duration of 5 years. However, when we look at desktop virtualization as shown

TABLE 3: Comparison of VM performance of hypervisor.

Hardware specification	CPU	Memory	Hard disk	Network card
Server	Intel(R) Core(TM) i7-2600 CPU 3.40 GHz × 2	ASint DDRIII 8G-1600 × 2	Seagate Barracuda 7200 1TB	RTL8169SC B7C33A5 GB29 TAIWAN (TG-3269)
Shared storage	Intel E5620 CPU 2.4 GHz * 1	8 GB DDRIII RAM	1TB SATA HDD	RTL8169SC B7C33A5 GB29 TAIWAN (TG-3269)

TABLE 4: Comparison of VM performance of hypervisor.

VM performance	Unix bench 5.1.3		Pass mark performance test 7.0			Composite index	Normalized composite index
	Ubuntu	CentOS	Win XP	Win Server 2003	Win 7		
ESXi 5.0	1540.7	1550.3	1026.4	1126.1	1108.8	1316.3	1
Hyper-V R2	1619	1629	1213.4	1328.3	1318.9	1455.4	1.11
Proxmox VE	1411.8	1427.3	1013.3	750.9	976.4	1166.7	0.89
KVM	1411	1427	730	688.4	902.7	1096.4	0.83
Xen	1094.6	1084.7	700	597	860.3	904.2	0.69

FIGURE 10: ROI histogram of server consolidation.

FIGURE 12: ROI histogram of desktop virtualization.

FIGURE 11: TCO histogram of desktop virtualization.

FIGURE 13: C/P ratio of hypervisor.

TABLE 5: Comparison of storage-accessing speed performance.

Storage-accessing speed performance	Timing cached reads (MB/sec)	Timing buffered disk reads (MB/sec)	Composite index	Normalized composite index
ESXi 5.0	11007.21	11.16	2210.4	1
Hyper-V R2	10475.72	9.33	2102.6	0.95
Proxmox VE	10287.88	9.98	2065.6	0.93
KVM	10503.85	9.75	2108.6	0.95
Xen	10160.47	9.55	2039.7	0.92

TABLE 6: C/P ratio of hypervisor (cost unit: US\$).

Hypervisor	Composite index	Operation cost	C/P ratio	Operation cost	C/P ratio	Operation cost	C/P ratio
		$\alpha = 0.5, \beta = 0.5$		$\alpha = 0.2, \beta = 0.8$		$\alpha = 0.6, \beta = 0.4$	
ESXi 5.0	1517.8	12,667	8.3	12,667	8.3	12,667	8.3
Hyper-V R2	1640.3	8,656	5.3	6,449	3.9	9,391	5.7
Proxmox VE	1423.5	3,560	2.5	1,896	1.3	4,115	2.9
KVM	1385.6	3,718	2.7	2,149	1.6	4,241	3.1
Xen	1228.6	4,373	3.6	3,197	2.6	4,765	3.9

in Figures 11 and 12, Proxmox VE outperforms the others to achieve the best ROI over a 5-year duration, even though its TCO is a little bit less than ESX's TCO. In addition, Proxmox VE would not only be the best choice to save the initial investment to own a virtual server infrastructure with better ROI in desktop virtualization, but it also obtains the lowest C/P ratio. This paper does not mention the security issue for virtual machines, which is related to access control [19] and cryptograph in VMs [20]. It can be explored in the further work.

6. Conclusions

The objective of this paper is to explore several critical issues of virtual server/desktop infrastructure such as server consolidation, virtualization performance, virtual machine density, total cost of ownership (TCO), and return on investments (ROI). Thus, this paper introduces five distinct well-known hypervisors installed in VSiC and has proceeded with an empirical analysis of server consolidation and desktop virtualization. As a result, even though ESX server gets the highest ROI and the lowest TCO in server virtualization and Hyper-V R2 gains the best performance over all, both of them cost too much; instead Proxmox VE would not only be the best choice to save the initial investment to own a virtual server infrastructure with better ROI in desktop virtualization, but also it obtains the lowest C/P ratio. We drew the conclusion that Proxmox VE outperforms the other hypervisors operating in the virtual server/desktop infrastructure.

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References

- [1] B. R. Chang, H. F. Tsai, and C. M. Chen, "Evaluation of virtual machine performance and virtualized consolidation ratio in cloud computing system," *Journal of Information Hiding and Multimedia Signal Processing*, vol. 4, no. 3, pp. 192–200, 2013.
- [2] J. Hardy, L. Liu, C. Lei, and J. X. Li, "Internet-based virtual computing infrastructure for cloud computing," in *Principles, Methodologies, and Service-Oriented Approaches For Cloud Computing*, chapter 16, pp. 371–389, IGI Global, Hershey, Pa, USA, 2013.
- [3] Y. Haga, K. Imaeda, and M. Jibu, "Windows server 2008 R2 hyper-V server virtualization," *Fujitsu Scientific and Technical Journal*, vol. 47, no. 3, pp. 349–355, 2011.
- [4] A. Kovari and P. Dukan, "KVM & OpenVZ virtualization based IaaS open source cloud virtualization platforms: openNode, proxmox VE," in *Proceedings of IEEE 10th Jubilee International Symposium on Intelligent Systems and Informatics*, pp. 335–339, 2012.
- [5] S. M. S. Kimball and C. Bisciglia, "Cluster computing for web-scale data processing," *ACM SIGCSE Bulletin*, vol. 40, no. 1, pp. 116–120, 2008.
- [6] F. Guthrie, S. Lowe, and M. Saidel-Keesing, *VMware vSphere Design*, John Wiley & Sons, New York, NY, USA, 2011.
- [7] D. Sacks, "Demystifying DAS, SAN, NAS, NAS Gateways, Fibre Channel, and iSCSI," *IBM Storage Networking*, pp. 3–7, 2001.
- [8] I. Yakti and W. A. Salameh, "iSCSI (internet small computer system interface) for your startup," *International Journal of Information and Communication Technology Research*, vol. 20, no. 3, 2012.
- [9] J. M. Kurz, "Beyond ROI," *Value Management*, pp. 1–7, 2012.
- [10] M. Kornevs, V. Minkevica, and M. Holm, "Cloud computing evaluation based on financial metrics," *Information Technology and Management Science*, vol. 15, no. 1, pp. 87–92, 2013.
- [11] A. Beloglazov and R. Buyya, "Optimal online deterministic algorithms and adaptive heuristics for energy and performance efficient dynamic consolidation of virtual machines in Cloud

- data centers,” *Concurrency and Computation*, vol. 24, no. 13, pp. 1397–1420, 2012.
- [12] S. Simanta, G. A. Lewis, E. J. Morris, K. Ha, and M. Satyanarayanan, “Cloud computing at the tactical edge,” *Software Engineering Institute* 680, 2012.
- [13] B. K. Kim, K. W. Hur, J. H. Jang, and Y. W. Ko, “Feedback scheduling for realtime task on Xen virtual machine,” *Communications in Computer and Information Science*, vol. 266, no. 2, pp. 283–291, 2011.
- [14] VMware TCO/ROI Calculator, VMware, <http://roitco.vmware.com/vmw/>.
- [15] Frequently Asked Questions, *Report of VMware ROI TCO Calculator, Version 2.0*, VMware, 2013.
- [16] TANEJA Group Technology Analysis, “Evaluating the ESX 4 Hypervisor and VM Density Advantage,” *Technology Validation*, pp. 1–12, 2009.
- [17] M. Tabuchi, K.-I. Itoh, Y. Nomura, and H. Taniguchi, “Design and evaluation of a system for running two coexisting linux systems,” *Electronics and Communications in Japan*, vol. 90, no. 9, pp. 56–68, 2007.
- [18] M. Aboutabl, A. Agrawala, and J. D. Decotignie, “Temporally determinate disk access (extended abstract): an experimental approach,” *ACM SIGMETRICS Performance Evaluation Review*, vol. 26, no. 1, pp. 280–281, 1998.
- [19] S. Prabhakar, S. Pankanti, and A. K. Jain, “Biometric recognition: security and privacy concerns,” *IEEE Security and Privacy*, vol. 1, no. 2, pp. 33–42, 2003.
- [20] R. L. Krutz and R. D. Scott Lowe Vines, *Cloud Security: A Comprehensive Guide to Secure Cloud Computing*, John Wiley & Sons, New York, NY, USA, 2010.