Utilizing Cloud Computing Services in Teaching and Research

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Abstract
Universities and research institutes suffer from limitations on the current services provided by their traditional IT infrastructures to all their various end users. Also, overheads, which are caused by managing, upgrading and maintaining all the traditional IT components and services, are very high compared to virtual infrastructures. Utilizing cloud technology can help enhance the learning experience in higher education. Integrating VDI platforms and hyper- visors can build virtualizaion environments to provide VDs. Thus, when applying virtualization to an infrastructural environment, is it better for universities and research institutes to adopt and utilize a specific VDI platform along with its suitable hypervisor. This article proposes and evaluates such a vision to utilize cloud computing services in teaching and research.

Key words:
Cloud computing, virtualization, virtual desktops, VDI

1. Introduction

Enhancing the educational and research environments in universities and research institutes is continually challenging. A migration to a virtual environment would be the sole best solution nowadays. Many respective features of virtualization, which traditional environments do not contain, can be employed for improving the learning process and the research activity. Universities and research institutes suffer from limitations on the current services provided by their traditional IT infrastructures to all their various end users. According to [1], [2] and [3], organizations in general are faced with cuts in their budgets. This causes some traditional IT resources of data centers to be used for a longer time and become outdated due to inability to upgrade them. There are other difficulties in the traditional data centers. They suffer from inflexibility due to their stationary nature and it is difficult to make modifications to physical servers without resulting in interrupted services. Also, the data stored in the data centers cannot be updated in real time, as stated in [4]. In addition to [4], [5] and [3] describe the managing process of the traditional data center IT resources by the IT support team as being a troublesome task to overcome. According to [6], [7] and [8], the end users' devices connected to the traditional data center are maintained by themselves which raises the difficulty in managing and controlling these devices by the IT staff. As a result, many resources of the end users' computers, which are out of data center's control, are utilized in a very limited manner by the end users and therefore significant time and effort is necessary for handling maintenance complexity and system scalability. In addition, traditional data centers mainly provide on-premise access based services and avoid public access based services due to their high security risks.

For this reason, many educational organizations have adopted cloud computing, in particular, educational institutions specializing in teaching and research. Thus, cloud computing can be utilized in teaching and research for allowing the contents of various courses and computing resources to be available constantly for students and faculty members to access remotely from either on-campus or off-campus, as stated in [1] and [8]. Furthermore, according to [6], [8] and [3], one of the main reasons that educational organizations have been attracted towards cloud computing is the sharp reduction of expenses. For instance, a software licensing model, which is pay-per-use, can be utilized by educational organizations in order to reduce costs.

Licenses can thereby be utilized in a cost-efficient manner according to student use or disuse. Also, money can be saved by the lower consumption of electricity that cloud computing technologies can offer.

This motivated us to dive deep into desktop virtualization environments in order to determine the abilities and services of Virtual desktop infrastructure (VDI) that education and research can utilize in order to enhance the learning experience in universities and institutes. We also carried extensive experiments to test the suitability of two well-known commercial VDI platforms in the market, produced by VMware and Citrix, for the best use in educational and research environments in terms of performance.

2. Related Work

In [1], authors used a Microsoft VDI platform on a Hyper-V hypervisor from the Microsoft vendor for their experiments. The Microsoft Hyper-V hypervisor works only on a Type 1 architecture and it is closed- source. Also, the comparison to other different hypervisors along with their corresponding VDI platforms is not taken into account. In addition, the experiments conducted in this paper is considered homogeneous. The evaluation of their experiments have been done using a benchmarking software tool in terms of network load monitoring but the specific name of the tool is not mentioned in the paper.

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The authors of [7] have only mentioned a XenDesktop VDI platform on a XenServer hypervisor from the Citrix vender without stating any specific details about whether the experiments have been implemented or not. The Citrix XenServer hypervisor works only on a Type 1 architecture and it is closed-source. Also, the comparison to other different hypervisors along with their corresponding VDI platforms is not taken into account. In addition, the experiments conducted in this paper are all considered homogeneous. There is only an evaluation in terms of budget costs but no benchmarking tool have been used for the sake of the objective evaluation.

The research done in [5] used a Horizon VDI platform on a vSphere hypervisor from the VMware vendor. The VMware vSphere hypervisor works only on a Type 1 architecture and it is closed-source. Also, The comparison to other different hypervisors along with their corresponding VDI platforms is not taken into account. In addition, the experiments conducted in this paper are all considered homogeneous. For their experiments, no benchmarking software tool has been used for the sake of evaluation.

Authors in [8] have only implemented but not evaluated the well-known VDI platforms, which are Citrix XenDesktop, VMware Horizon and Microsoft VDI. They work only on a Type 1 architecture and they are all closed-source. However, the authors did not specify in the paper the hypervisors used for their experiment on which the different VDI platforms have been installed in order to find out whether they implemented a homogeneous or heterogeneous experiment. Therefore, the experiments in the paper have not been counted in the following summary. In their experiments, no benchmarking software tool has been used for the sake of evaluation.

Paper [4], however, has only concentrated on evaluating hypervisors rather than VDI platforms. Both types of source code are included; open-source hypervisors, which are Proxmox VE, Ubuntu KVM and CentOS Xen, as well as closed-source hypervisors, which are VMware vSphere and Microsoft Hyper-V. The evaluation of these hypervisors has been done by using various metrics in different ways. They have used virtual machines instead of virtual desktops in their experiments for evaluating the hypervisors. However, some other papers as in [9], [10], [11] and [12], have not given any details about the types of hypervisors or the VDI platforms used.

Research done in [3] has tested and evaluated only virtual machines on top of a hypervisor. The hypervisor used is Oracle VirtualBox and this only works on Type 2 architecture. The core objective is to test the performance between different guest operating systems, which are Windows and Linux as virtual machines not as virtual desktops.

In [13], authors have used a XenDesktop VDI platform on a XenServer hypervisor from the Citrix vendor and also a Horizon VDI platform on a vSphere hypervisor from the VMware vendor. In addition, they have conducted experiments using a XenDesktop VDI platform on a vSphere hypervisor. The Citrix XenServer and VMware vSphere hypervisors work only on a Type 1 architecture and they are closed-source. Also, the comparison to other different hypervisors along with their corresponding VDI platforms is indeed taken into account. In addition, the experiments conducted in this paper are all considered homogeneous as well as heterogeneous in only one side. The evaluation of their experiments have been done using two benchmarking software tools in terms of a workload simulation and the specific names of the tools are mentioned in the paper which are Microsoft Remote Desktop Load Simulation and Login VSI.

Researchers in [14], [15] have only used a XenDesktop VDI platform on a XenServer hypervisor from the Citrix vender for their experiments. The Citrix XenServer hypervisor works only on a Type 1 architecture and it is closed-source. Also, the comparison to other different hypervisors along with their corresponding VDI platforms is not taken into account. Also, the experiments conducted in this paper are all considered homogeneous since the hypervisor and VDI platform used are both compatible and come from the same vendor. However, an experiment to be considered heterogeneous is that the hypervisor and VDI platform used are both compatible but come from different venders. The evaluation of their experiments have been done using a benchmarking software tool in terms of a network emulator and the specific name of the tool is mentioned in the paper which is Wlinee.

3. Virtualization Architectures

In the Type 1 Hypervisor, both environments of VMs and VDs can be used in the same hardware of a server in parallel working separately together at the same time. The main use of hypervisor Type 1 is to provide different virtual environments in production to the end users by utilizing the full components of the physical hardware resources.

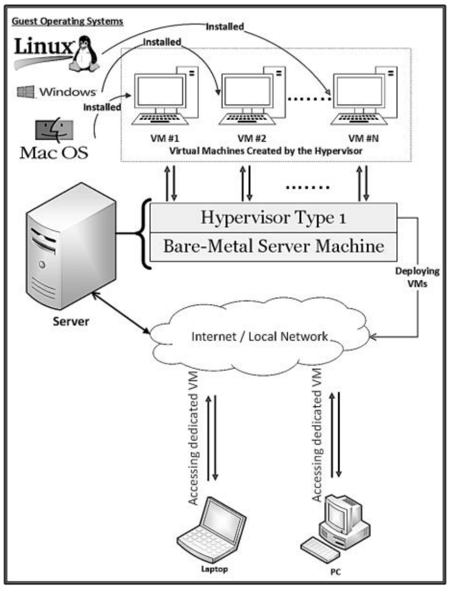

Fig. 1 The Virtual Machines Architecture on Type 1 Hypervisor

However, Type 2 uses a general-purpose or full operating system as a foundation for its virtual environ- ment. As shown from the right part above in (B), the only difference is that a hypervisor is just running on top of an operating system, which is called “a host”, rather than running on the hardware directly. The Type 2 hyppervisor is mainly used by software or operating system developers in order to help them design their applications on various types of operating system platforms or to test or use a variety of old and new versions of different operating systems installed on VMs. This allows the use of a single physical machine instead of having many physical machines in order to run a number of operating systems at the same time, leading to the consumption of much power, occupying a large space and costing a lot of money.

A. The Architecture of Virtual Machines

In order to obtain a full picture of how VMs and VDs work, both architectures should be illustrated and described.
The architecture of VMs of Type 1 hypervisor consists of a layer of the hardware of a server, a layer of a hypervisor and a layer of VMs. The special hypervisor of Type 1 exists upon the hardware. Therefore, the roles of the hypervisor are to create, run and manage VMs as well as managing the hardware resources. All the VMs, which are created by the hypervisor, will be isolated from each other and can be installed by a variety of operating systems. As shown in Figure 1, the deployment of VMs to the end users is achieved by the hypervisor. Also, the access to VMs is through the server itself in which VMs have been created by the administrator. The server is accessed via a local network or the internet using only laptops or PCs.

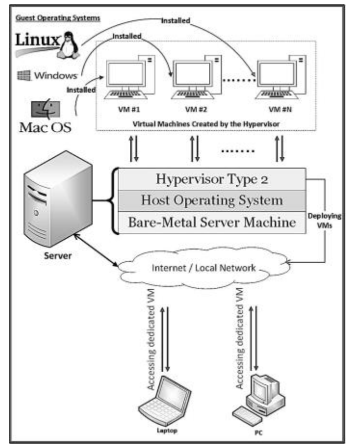

Fig. 2 The Virtual Machines Architecture on Type 2 Hypervisor

The architecture of VMs of Type 2 hypervisor consists of a layer of the hardware of a server, a layer of a host operating system, a layer of a hypervisor and a layer of VMs. The special hypervisor of Type 2 is installed upon the host operating system as opposed to the hypervisor of Type 1. However, the roles of the Type 2 hypervisor are still the same except that managing and controlling all the hardware resources is carried out by the host operating system instead in this architecture. All the VMs, which are created by the hypervisor, will be isolated from each other and can be installed by a variety of operating systems.
As shown above in Figure 2, the deployment of VMs to the end users is achieved by the hypervisor. Also, the access to VMs is through the server itself in which VMs have been created by the administrator. The server is accessed via a local network or the internet using only laptops or PCs.

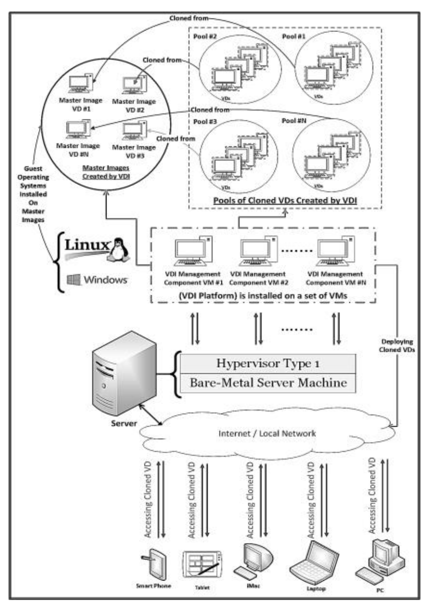

Fig. 3 Virtual Desktops Architecture

B. The Architecture of Virtual Desktops

The architecture of VDs is composed of a layer of the hardware of a server, a layer of a hypervisor and a layer of VDI platform installed on a set of VMs. The roles of VDI are to create, run and manage master images on which guest operating systems will be installed as well as the pools of empty VDs that will be cloned to different master images according the VDI administrator's configurations. The VDI platform can only be applied on the Type 1 hypervisor. Also, the VDI platform has been only used since it was created for providing Windows operating systems exclusively. Nowadays, it can provide Linux based VDs as well. The deployment of VDs to the end users is achieved by the VDI platform.
The access to cloned VDs is through the server itself on which VDs have been created by the administrator using the VDI platform console. The server is accessed via a local network or the internet. Various devices are used for accessing the VDs, such as laptops, PCs, iMacs, tablets and smart phones instead of access by limited devices as in the VM architecture, as shown in Figure 3.

C. Login VSI as a Benchmarking Software Tool

As stated in [16], "Login Virtual Session Indexer (Login VSI) is the industry standard benchmarking tool for measuring the performance and scalability of centralized desktop environments such as Virtual Desktop Infrastructure (VDI) and Server Based Computing (SBC)". It is mainly and only used for Windows based environments. Login VSI is helpful as a benchmarking tool for finding the maximum number of users the VDI environment can handle without any degradation in performance.
Also, Login VSI is useful for deciding which hardware configurations are better to be set in order to support a desired certain number of users and desktop applications. Upon any software or hardware change that is made to the VDI environment, Login VSI tests are able to predict how much impact would be on the performance either negatively or positively.
The Login VSI needs two machines on which to work. The first machine is called Dataserver/VSIshare where the Login VSI software tool will be installed as a management console for tests to be configured. In addition to it another software component will be installed in the same machine for automatically analyzing the results being collected from the tests and it is called Analyzer. The second machine is called Launcher which launches actual test sessions in the target VDI environment and load these sessions by various workloads from the files stored in the Dataserver machine.

4. Performance Evaluation

A. Experimental Architecture

It is really necessary and important that virtual desktops, running on any possible platforms, should be evaluated in order to let an organization decide whether adopting VDI as a reliable computing environment is the best choice within its environment. Hence, some well-known VDI proprietary products, which mainly provide virtual desktop environments, require evaluation particularly in terms of performance. Therefore, several experiments will be designed and implemented for this purpose based on two different workloads and two inter-arrival times. The total number of experiments which will be conducted is six. All of the experiments conducted are going to be homogeneous. The homogeneous experiments are a VMware Horizon VDI platform installed on a VMware vSphere hypervisor and also a Citrix XenDesktop VDI platform installed on a Citrix XenServer Hypervisor. All these VDI environments are running directly on top of identical separate bare-metal servers.
The aim is to conduct a comparative study for two different VDI platforms running onto two different hypervisors and they eventually form two separate homogeneous environments which will be subject to evaluation. As a proposed approach, two similar experimental structures are designed in order to achieve a fair assessment of their own performance as they are shown in Figure 4.

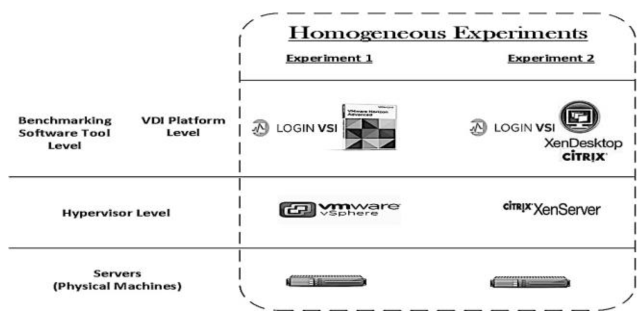

Fig. 4 The Abstract Levels of the Experimental Design

B. Experimental Description

The first step towards implementing VDI virtualization environments is to install a software hypervisor directly on top of the hardware, usually on powerful servers. The next step is to implement a complete VDI platform that must be implemented on the Type 1 hypervisor within some of its operating-system-based virtual machines in order to provide virtual desktops as a service. Finally, a benchmarking software tool must be installed on an isolated virtual machine or a stand-alone physical machine so that all the virtual desktops running can be monitored and their performance can be evaluated based on available metrics in the benchmarking software tool. Each experiment will be conducted in an identical separate server so that all the hardware resources of the server will be fully dedicated to the VDI environment and the results obtained can be fairly and reliably analyzed. Tables 1, 2, and 3 summarize the parameters used in our experiments.

Table 1: The general parameters of the experiments

Number of VDs	Workload Types	Inter-Arrival Time	Test Duration
10	Light or Heavy	2.5 or 5.0 Minutes	26 or 50 Minutes
20	Light or Heavy	Only 2.5 Minutes	50 Minutes

Table 2: The total number of systematic experiments

Experiment #	# of VDs	Workload Type	Inter-Arrival Time
Experiment 1	10	Light	2.5 Minutes
Experiment 2		Heavy	2.5 Minutes
Experiment 3	10	Light	5.0 Minutes
Experiment 4		Heavy	5.0 Minutes
Experiment 5	20	Light	2.5 Minutes
Experiment 6		Heavy	2.5 Minutes

C. Experimental Infrastructure

For the sake of conducting the proposed experiments, there will be five servers that need to be allocated. All the experiments can be only conducted sequentially not in parallel at the same time. However, one server will be dedicated to the benchmarking tool installed and running on it for simulating end users' behaviours by invoking various workloads and monitoring the VDs in a session. Table 3 describes the hardware specifications of the five servers used.

Table 3: The hardware specifications of the five servers

Specifications	Server #1	Server #2	Server #3	Server #4	Server #5
Hardware Model	Intel Xeon				
Processor Speed	2 GHz				
CPU Processors	12 Cores				
Logical Processors	24 cores				
Main Memory	64 GB	96 GB	64 GB	96 GB	32 GB
Storage Capacity	1.08 TB				280 GB

Table 4: the software specifications installed on the five servers

Software	Type	Version	Installed Location
VMware vSphere	Hypervisor	6.5	Servers: #1 and 2
Citrix XenServer		7.0	Servers: #3 and 4
VMware Horizon	VDI platform	7.0	Server #1
Citrix XenDesktop		7.9	Server #3
VMware vSphere Client	Administrating Tool	6.5	Administrator Machine
Citrix XenCenter Client		7.0	Administrator Machine
Login VSI	Benchmarking Tool	4.1	Server #5
Microsoft Windows Server	Operating System	2012 R2	Servers: #1,3 and 5
Microsoft Windows		8	Server #5
Microsoft Windows		7	Servers: #2 and 4

In Table 4 above, two hypervisor types only are used: Citrix XenServer and VMware vSphere along with their administrating clients. Also, the two VDI platforms used are Citrix XenDesktop and VMware Horizon. The benchmarkng tool is a commercial product, Login VSI. In addition, three versions of the Windows operating systems will be used: Windows server 2012 R2, 8 and 7.

D. Experimentation Objectives

After conducting all the experiments and measuring the performance of each VDI platform, two objectives will be achieved. The first objective is to collect significant results from the evaluation process and to compare them between each other. These results will lead to a conclusion that will help an organization to decide the best one to use in its own infrastructure if the VDI environment does not exist or to change the VDI environment which already exists to the better choice. The last objective is to add this research outcome to the literature as a reference for the future, in order to facilitate performance comparisons of VDI environments produced by alternative venders. In addition, the literature will allow the same experiments to be repeated for the sake of validating collected results conducted by this research.

E. Assumptions and Limitations

As valid assumptions, the work in this thesis will be limited to the following assumptions. The assumptions are the network used, the VDI platform version, the workload type and the operating system platform. All of theses assumptions will be discussed in detail in the following paragraphs stating the limitations along with each one of them.

For the network used, the experiments were conducted within a local area network as a private cloud into the university campus. Therefore, the impact of the network on the main service, which is the virtual desktop, provided by the VDI platform can be negligible. As a limitation, the results collected indicate certain conclusions which cannot be generalized. In order to measure the impact of the network within either hybrid or public clouds, further investigation needs to be done by using specific benchmarking tools for network measurements.

For the VDI platform version, the experiments were built using specific VDI versions of VMware and Citrix. At the time of use for the experiments, they were the latest versions. However, the results collected indicate certain conclusions which cannot generalized as a limitation. Each time the vendors (VMware and Citrix) release new versions of their products, the same experiments must be conducted for the sake of validating the current results in the thesis to overcome such limitation.

For the workload type, the experiments conducted have used only two types of the predefined Login VSI workloads. These workloads have been specifically designed to use some certain desktop applications. Therefore, the results collected will be only based on such workloads as a limitation. Although the workloads used in the experiments are deterministic, other workloads can be customized based on the requirements needed for various environments. The Login VSI benchmarking tool allows the educational organizations to construct their workloads according to their needs. The results that will be obtained most probably will be different than the results of this thesis due to using a variety of other desktop applications.

For the operating system platform, the experiments conducted have been based on only only Windows platform. Also, only one version is particularly used, which is Windows 7. Therefore,the results collected cannot be generalized as a limitation. In order to overcome such limitation, other versions of Windows platform should be included for testing. Also, since VDI can support now Linux platform and universities an research institutes need this platform in their labs, the Linux platform should be used as a VDI platform but other benchmarking tool must be selected because the Login VSI benchmarking tool is mainly used in and for Windows platform as a performance assessment tool.

5. Results and Discussions

As importantly mentioned before, whenever the baseline becomes lower, the VDI environment will be better. Table 5 and Figure 5 illustrate clearly the accurate differences between the baselines of VMware and Citrix experiments.

Table 5: The summary of baseline comparisons between experiments.

Experiment #	VMware Baseline	Login VSI Rating	Citrix Baseline	Login VSI Rating	Difference
E1	1261 ms	Fair	2142 ms	Very Poor	-70 %
E2	949 ms	Good	1384 ms	Fair	-46 %
E3	1232 ms	Fair	2319 ms	Very Poor	-88 %
E4	982 ms	Good	1352 ms	Fair	-38 %
E5	1299 ms	Fair	2637 ms	Very Poor	-103 %
E6	1004 ms	Good	1589 ms	Fair	-58 %

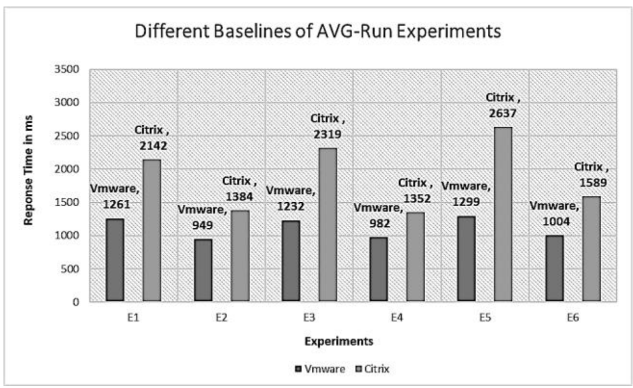

Fig. 5 The VMware and Citrix Baselines in AVG-Run Experiments.

Table 5 above shows the summary of baseline comparisons for all experiments. The aim is to extract the final result from these comparisons as a part of an answer to the thesis problem statement. Therefore, the result based on the baseline is that VMware VDI platform obviously outperforms Citrix VDI platform in all the six experiments, which are E1, E2, E3, E4, E5 and E6.

There are several important observations and conclusions which can be extracted from the diverse results of all the thesis experiments. They are related to the various runs for each VDI platform (VMware and Citrix), the differences between the baselines of VMware and Citrix and the differences between the maximum capacities (VSImax) of VMware and Citrix. They will be separately elaborated in the following paragraphs.

For the VMware runs of each experiment, it should be carefully noticed that there are no differences among the runs for each experiment starting from E1 up to E5. Moreover, all of VMware experiments except E6 have reached the maximum capacities according to their own tests. The meaning of existing no differences between runs and reaching the maximum capacities in the first five experiments is that the VMware VDI platform has a very high level of stability and reliability.

However, although the results of the runs of E6 are not constant presenting instability, there is a reasonable justification of what causes such variant results. Since the maximum number of the server hardware vCPUs can support as maximum is 24 enabling hyper-threading, the test of E6 consists of 20 VDs and each one needs 2vCPUs as a minimum requirement for executing its heavy workload. Therefore, 40 vCPUs are required in order to pass the test successfully and safely get stable and reliable results. Passing the test successfully is impossible due to unavailability of the minimum requirement of the hardware resources, namely enough vCPUs. For the Citrix runs of each experiment, it should be carefully noticed that there are differences among the runs for each experiment starting from E1 up to E6 except E3 and E4. Moreover, all of Citrix experiments except E3 and E4 have not reached the maximum capacities according to the results of their own tests. The meaning of existing differences between runs and not reaching the maximum capacities in the first and last two experiments is that the Citrix VDI platform has a very low level of stability and reliability.

According to the experiments E1, E2, E5 and E6, there is a single interpretation for not reaching the maximum capacities of their tests although the server hardware resources are enough and available. It seems that the Citrix VDI platform is sensible to handle the shrinking inter-arrival time tests, (2.5 M), which causes some virtual desktops to be in a stuck or inactive state due to rather high response times as a result of the massive requests coming from the VDs in a shorter time than the tests of 5.0 M inter-arrival time. In addition to the interpretation, E6 has also a reasonable justification of what causes such inconstant results which is unavailability of the minimum number of vCPUs in the server required for this specific experiment. However, the results of the runs of only E3 and E4 are almost constant presenting stability by reaching the maximum capacities of their tests.

The comparisons of the six experiments between VMware and Citrix VDI platforms in terms of VSImax and Baseline shows clearly that the VMware VDI platform outperforms the Citrix VDI platform within their homogeneous environment. Although the work in the thesis has been completed showing that the VMware VDI is better than the Citrix VDI, there is an important complementary work which should be accomplished by another researcher. It is difficult to precisely determine whether the thesis conclusion as a final answer to the problem statement based on the results of the experiments is because of either the VDI platform itself or the high compatibility with the hypervisor as a homogeneous environment. In order to partially find that, the same experiments of the Citrix VDI platform should be conducted on top of the vSphere hypervisor hypervisor on the same hardware specifications as a heterogeneous environment.

6. Conclusion and Future Work

In brief, what has been found and significantly noticed from the results of the experiments conducted as general observations is the following. The Citrix VDI platform is very sensible to the inter-arrival time of virtual desktops in the test whether it is shrinking or expanding for all the Citrix experiments conducted. However, the VMware VDI platform does not have any sensitivity to the inter-arrival time whatever it is in the test in all the VMware experiments conducted. Also, the Citrix VDI platform mostly has fluctuations in the maximum capacities of the tests between the runs for every Citrix experiment except E4. However, the VMware VDI platform greatly has stability in the maximum capacities of the tests between the runs for every VMware experiment except E6.

As a final important observation, whenever the number of virtual desktops in the same shrinking inter- arrival time test for the light workload increases the difference in performance in terms of the maximum capacity (VSImax) between VMware and Citrix will be also increasing in favour of VMware. However, whenever the number of virtual desktops in the same shrinking inter-arrival time test for the heavy workload increases the difference in performance in terms of the maximum capacity (VSImax) between VMware and Citrix will be inversely decreasing in favour of Citrix if and only if the number of vCPUs is less than what is required for the total virtual desktops in a test. For the expanding inter-arrival time test regardless of the type of workload, there will be no difference in terms of the maximum capacity (VSImax) between the VMware and Citrix. As a future work, the current work is limited by using products provided by only two venders. Therefore, this work can be expanded by including some other VDI platforms provided by other vendors to be evaluated as well. This will help universities and institutes to have wider options rather than only two from which the right choice can be easily and safely taken.

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