PERFORMANCE EVALUATION OF VDI-BASED PRIVATE CLOUD TECHNOLOGY FOR EDUCATION AND RESEARCH

BY

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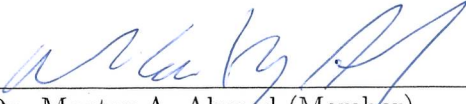## DHAHRAN 31261, SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

This thesis, written by **SALEH ABDULRAHMAN SALEH ALYAHYA** under the direction of his thesis adviser and approved by his thesis committee, has been presented to and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN COMPUTER SCIENCE**.
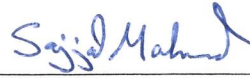
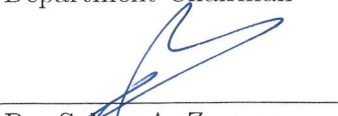**Thesis Committee**

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To

My parents Abdulrahman and Monirah,
who love me so much;
My wife Haifa and my children,
whom I love so much;
and all my brothers and sisters,
whom I share love with.

ACKNOWLEDGMENTS

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LIST OF ABBREVIATIONS

VD	Virtual Desktop
VDI	Virtual Desktop Infrastructure
VM	Virtual Machine
PC	Personal Computer
IT	Information Technology
SaaS	Software as a Service
DaaS	Desktop as a Service
PaaS	Platform as a Service
IaaS	Infrastructure as a Service
HW	Hardware
SW	Software
M	Minute
IAT	Inter-Arrival Time
SSD	Solid-State Drive
HDD	Hard Disk Drive

THESIS ABSTRACT

NAME: Saleh Abdulrahman Saleh Alyahya

TITLE OF STUDY: **Performance Evaluation of VDI-Based Private Cloud Technology for Education and Research**

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Enhancing the educational and research environments in universities and research institutions is continually challenging. Currently, educational organizations provide physical facilities to their staff and students. Such setups can be expensive, inflexible and difficult to maintain and suffer from the limitations on the services provided by their traditional Information Technology (IT) infrastructures to their various end users. Also, the overheads which are caused by managing, upgrading and maintaining all the traditional IT components and services are very high compared to virtualization environments. The aim is to utilize and to enhance one of the cloud computing technologies, Virtual Desktop Infrastructure (VDI), for supporting teaching and research activities within an educational organization. Cloud computing has redefined the view of computing resources as a framework where

these resources are provisioned dynamically on demand. With cloud computing, these resources can be delivered to users across geographical and time boundaries. For example, virtualization stores the resulting virtualized desktop on a remote central server, instead of on the local storage of a remote client; thus, when users work from their remote desktop client, all of the programs, applications, processes, and data used are kept and run centrally. Therefore, there is a variety of venders for varied VDI platforms and hypervisors by which virtualization environments can be built. Thus, when applying virtualization to an infrastructural environment, which VDI platform among others is suitable for universities and research institutes to be adopted within their educational environments? The performance evaluation for only two well-known VDI platforms as a research scope, VMware Horizon and Citrix XenDesktop, using Login VSI as a software benchmarking tool will be conducted by placing them in separate homogeneous architectural designs in this research project as a final answer to the important stated question.

ملخص الرسالة

الاسم الكامل: صالح بن عبد الرحمن بن صالح اليحيى.

عنوان الرسالة: تقييم الاداء لتقنية الحوسبة السحابية الخاصة المعتمدة على حواسيب أسطح المكتب الافتراضية للتعليم والبحث العلمي.

التخصص: علوم الحاسب الآلي والمعلومات.

تاريخ الدرجة العلمية: مايو ٢٠١٨.

يمثل تعزيز البيئات التعليمية والبحثية في الجامعات ومعاهد البحوث تحدياً مستمراً. حالياً، المنظمات التعليمية تقدم وسائل مادية حقيقية لمنسوبيها من أعضاء هيئة التدريس والطلاب. هكذا تكوينات في بيئات تعليمية تعتبر مُكلفة وغير مرنة وكذلك يصعب صيانتها وتعاني الجامعات ومعاهد البحوث من القيود المفروضة على الخدمات التي تقدمها البنية التحتية لتكنولوجيا المعلومات التقليدية إلى المستخدمين في كل المجالات ومنها النفقات العالية. والتي كان سببها الإدارة، وتطوير، وصيانة المكونات، حيث تعتبر خدمات تكنولوجيا المعلومات التقليدية مُكلفة جداً بالمقارنة مع البنية التحتية الافتراضية. الغاية هي أن تُستخدم بشكل أمثل أو تُعزز بأحد تقنيات الحوسبة السحابية، البنية التحتية لسطح المكتب الافتراضي VDI، لدعم التدريس وأنشطة البحث العلمي ضمن أي منظمة تعليمية. الحوسبة السحابية قد أعادت تعريف النظرة إلى موارد الحوسبة كإطار عمل حيث توفَر هذه الموارد بطريقة حيوية عند الطلب. بالحوسبة السحابية، تلك الموارد التي يتم إيصالها للمستخدمين تكون عابرة للحدود الجغرافية والوقت. على سبيل المثال، البيئة الافتراضية تخزن السطح المكتبي الافتراضي الناتج من على خادم مركزي عن بعد، بدلاً من التخزين المحلي في جهاز العميل عن بعد، وبالتالي عندما يعمل المستخدمين من سطح مكتب عميل افتراضي عن بعد، كل البرامج والتطبيقات والعمليات والبيانات المستخدمة تصبح محفوظة ومُشغلة مركزياً. ولذلك، هناك مجموعة متنوعة من البائعين لمنصات VDI وبرامج Hypervisor التي يمكن أن تبني البيئات الافتراضية. وبالتالي، عند تطبيق التمثيل الافتراضي لبيئات البنى التحتية، أي منصة VDI من بين منصات أخرى هي الأنسب للجامعات ومعاهد البحوث من الممكن أن يتم تبنيها ضمن بيئاتها التعليمية؟ تقييم وفحص الأداء لأبرز منصتين في البنية التحتية لسطح المكتب الافتراضي فقط كنطاق بحثي، وهما VMware Horizon و Citrix XenDesktop، باستخدام Login VSI كأداة فحص برمجية هو ما سيتم إجراؤه بوضعهما في تصميمات بنيوية متجانسة مستقلة في هذا المشروع البحثي كإجابة نهائية على السؤال الهام المذكور آنفا.

<h1 style="text-align:center">CHAPTER 1</h1>

<h1 style="text-align:center">INTRODUCTION</h1>

1.1 Overview

Data centers are mainly used in diverse domains. These data centers are basically owned by organizations either governmental, commercial, medical or educational. The major aim of owning such data centers for the organizations is to provide IT services and applications to their end users by which productivity can be enhanced. However, current IT services associated with the traditional data centers are insufficient for overcoming some challenges which have been impossible to be realized in the past. The challenges are specifically described as in the two following paragraphs.

According to [2], [6] and [11], 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. Also, limited budgets result in an inadequate quantity of devices needed by data centers.

Also, [6] and [10] mention high costs associated with current IT infrastructures of traditional data centers. For instance, traditional IT infrastructure requires significant electricity to operate its wide machines and devices leading to higher power bills.

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 [5]. In addition to [5], [9] and [11] 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 [7], [8] and [10], 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.

Nowadays, cloud computing is the next phase of the data centers. In order to change the traditional infrastructures built in the organizations to the cloud computing infrastructures, only two main tasks have to be accomplished. The first task is to apply virtualization. Second, a console must be designed and

implemented so that each user can access that console to request cloud computing services, such as hardware resources, a variety of operating systems, software applications, and then they have to be provisioned to the end user dynamically and automatically without any intervention by the IT data centers' technical staff. Consequently, cloud computing is becoming the ideal computing engine for many organizations because of its invaluable benefits.

By having cloud computing applied in the data centers, the real data will be highly secured since every single data unit in the cloud is being centralized in the data center and nothing exists in the end user terminals, as stated in [2] and [3]. Also, according to [2], [3], [5], [6] and [10], cloud computing plays a major role in reducing costs. As a real example, existing servers will be consolidated to provide a variety of services instead of only one server for each service as in traditional infrastructure, but also thin client devices, which consume less power (about 40 watts per device), will be utilized rather than PCs, which consume 300 watts. Doing so, this will certainly result in cost saving. Moreover, cloud computing simplifies the managing process of all data center's IT resources since the management is done centrally by the IT support team, as stated in [6] and [11].

Cloud computing has other features. As mentioned in [3], [5], [6] and [11], cloud computing can improve scalability, agility, flexibility, space saving, security and performance. Efficiency is fulfilled in cloud computing as well. According to [8] and [10], cloud computing is able to decrease cost and effort sharply when

replacing IT computing resources. Also, the elasticity of provisioning cloud computing services is achieved to meet dynamic demands and to utilize the cloud resources efficiently. In addition, as in [9] and [10], transferring to a cloud computing infrastructure from current traditional IT infrastructure is generally easy. The independence of cloud computing is realized since all types of cloud computing services can be accessed regardless of the locations because cloud computing depends mainly on a network-based access.

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 [2] and [10]. Furthermore, according to [7], [10] and [11], 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. In cloud computing, all educational services are residing on servers which are centrally administrated. As a result, virtual labs can be easily implemented and deployed for students and instructors and therefore the educational environment will always be ready faster

than the traditional environment. In addition, the educational organizations employing cloud computing will be relived from managing their IT infrastructures, which leads to time and effort saving as well. Teaching and administration can be the priority. Moreover, The security is enhanced in the educational services based on cloud computing when one server is being affected by a virus other servers will be isolated from that affected server.

Educational and research activities are supported by many cloud technologies. However, one of the most significant cloud technologies is known as VDI, which has been applied in many educational environments because of its great advantages. According to [2], [3], [4], [6], [7] and [9], The security risks of VDI are highly minimized. This is because VDs and end users' data are stored centrally on servers. As a result, VDI can provide better control to its many VDs because of the central management by the IT technical support team and reliving end users from maintaining their personal computers by themselves. Also, VDI uses SSL encryption in the connection to its VDs. In addition, VDI can be the best solution for the compatibility issue between applications and different versions of Windows operating system. Furthermore, VDI is a helpful technology for reducing costs. This can be done by utilizing thin client devices rather than PCs and also existing computers can be used without the need for upgrading their hardware resources, as stated in [11]. Also, VDI utilizes virtulaization to consolidate all VDs to be working on only one server, reducing the power consumption.

Other VDI features, as in [4], [5], [6], [7], [9] and [11], are flexibility and availability. Flexibility in VDI is achieved when end users, either students, instructors or staff, can use different terminals to run their VDs for carrying out their tasks and they all receive the same environment. Availability in VDI is meant for allowing remote access to VDs regardless of the time, place or device used as well as the type of operating system for accessing these VDs. Thus, the access to VDs can be practically unlimited making the workspace for end users very wide.

According to [7], [10] and [11], VDI can save time and effort for the IT technical team since they will be able to deploy many VDs in a very short time, "120 VDs in 40 minutes", as stated in [9]. Also, test or production environments can be implemented in a faster and easy manner by VDI. Furthermore, the environments provided on VDI will be unified and identical for all end users, especially when installing and updating the master images linked to a set of VDs and these images can be copied and shared among various subject contents. Building virtual labs is an easy task on VDI and therefore physical labs can be changed to be virtual labs while these physical labs can be utilized to be other classrooms or offices. Finally, VDI is capable of performing backups and maintaining VDs faster and easier than the traditional technologies.

However, there are some disadvantages of using VDI, as stated in [4]. VDI is a network-based technology and therefore its performance will be subject to the bandwidth of the network used. Furthermore, if all VDI configurations and setting

are successfully completed but the network on which VDI works is not appropriately assigned, or encounters some technical issues the whole VDI environment will collapse. In addition, the VDI technology suffers from a single point of failure. However, this issue can be solved due to its flexibility feature by migrating the running VDs on the halted server in time to another active server which has an identical VDI platform environment in order to keep them continuously running regardless of the server used.

1.2   Motivation

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.

As known, universities and research institutes in reality are not usually interested in utilizing open-source virtualization environments within their local data centers due to many factors. The main reason is that they always need support, updates and maintenance for their new virtual IT infrastructures to provide persistent, stable services to their faculty members, students and researchers. This makes choosing only proprietary venders more significant. Therefore, the scope of this work will be limited to the two well-known venders in VDI virtualization, *Citrix* and *VMware*. Moreover, the computer-science courses model will be only
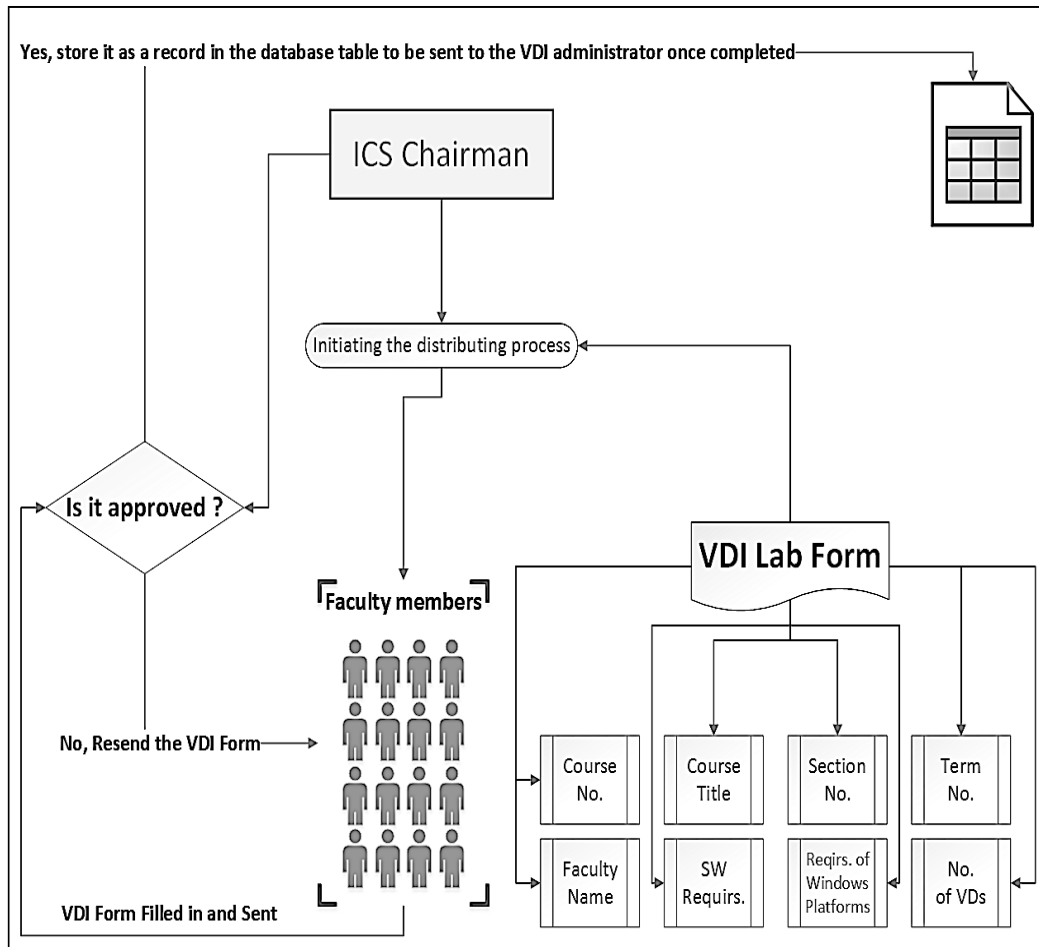
Figure 1.1: The Preliminary Step for the VDI Model of Computer Science Courses

used and applied, as shown above in Figure 1.2, although the same model can be generalized to include different subjects or disciplines. The suitability for both products applying different implementation is going to be measured in terms of performance and analyzed as an answer to the problem statement mentioned in Section 1.5.

Undergraduate Students

Faculty members

A Pool of Configured Cloned Virtual Desktops

Active Directory for each Course Group

ICS202-01   ICS-202-02   ICS410

User Profiles

VDI Administrator

A Pool of Configured Master Images for each Course

ICS410   ICS324
ICS202   ICS431

The Database Table Sent by the ICS Chairman

Courses	SW Requirements	Platform Requirements	# of VDs	Sections
ICS 202	java eclipse	Windows 7,8 or 10	25	2
...	...	...	...	...
ICS 410	Prog, Lisp, Haskell, C	Windows 7	30	1
...	...	...	...	...

Figure 1.2: The VDI Model of Computer Science Courses for Students and Faculty Members

1.3   Contributions

Until Now, studies of VDI platforms have mostly been homogeneous in nature; that is, experiments have been conducted, due to high compatibility, using softwares from the same vender only. The main contribution of this work, however, will be to concentrate on evaluating two different homogeneous VDI platforms considering various performance parameters by using Login VSI as a benchmarking tool among others since it is a standard VDI benchmarking tool and used by large organizations and companies. This thesis seeks to help universities and re-

search institutes for choosing the most feasible VDI platform among the selected ones in order to provide DaaS technology within their IT environments for their faculty members, researchers and students.
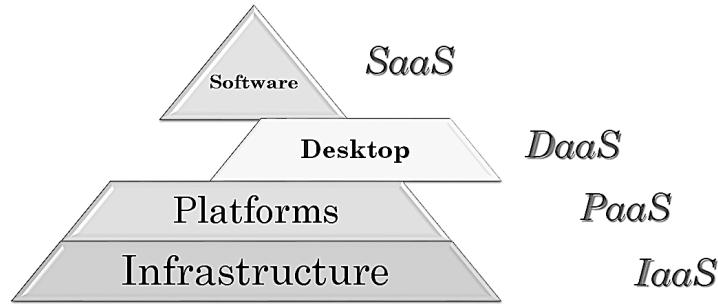
Figure 1.3: The New Cloud Computing Structure for The Service Layers

Also as another contribution, the VDI-based cloud technology is providing DaaS *VDs.* The cloud computing consists of only three service layers in its main structure. They are IaaS, PaaS and SaaS. The DaaS has been coined as an additional layer to the cloud computing structure to be four layers rather than the current three layers and all can be provided for educational and research institutes according to their needs, as shown in Figure 1.3. DaaS does not fall under SaaS or PaaS cloud service layers. The reason is that DaaS does not provide the end user with a pure VM where the user can have the full control of that VM to perform privileged tasks on it as an administrator as PaaS does. Also, DaaS is much more versatile than SaaS because SaaS provides specific desktop applications like MS Word, Eclipse and others offered by the SaaS provider in which the end user can only utilize them for their own files but at the same time the user will not be able to use or install other desktop applications in such an environment. Therefore, DaaS has indeed this flexibility in its own environment for the end user.

1.4   Research Objectives

1. Diving deeply into desktop virtualization environments in order to determine the abilities and services of VDI that education and research can utilize in order to enhance the learning experience in universities and institutes.

2. Testing the feasibility of two well-known commercial VDI platforms in the market, produced by VMware and Citrix, for the suitable use in educational and research environments in terms of performance.

1.5   Problem Statement

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. There is a cloud technology that can help enhance the learning experience in higher education, called VDI. Therefore, there is a variety of venders for varied VDI platforms and hypervisors by which virtualizaion environments can be built to provide VDs. Thus, when applying virtualization to an infrastructural environment, is it feasible for universities and research institutes to adopt and utilize a specific VDI platform along with its suitable hypervisor among two popular VDI vendors?

1.6 Thesis Organization

The following chapters will be organized as follows. The second chapter is dedicated for the background. For the third chapter, the related work is thoroughly reviewed whereas the forth chapter discloses the research problem and the methodology. In the last two chapters, the experiments along with their analyzed results will be elaborated as well as the conclusion with future work will be presented at the end of the thesis.

CHAPTER 2

BACKGROUND

2.1 Virtualization Architectures
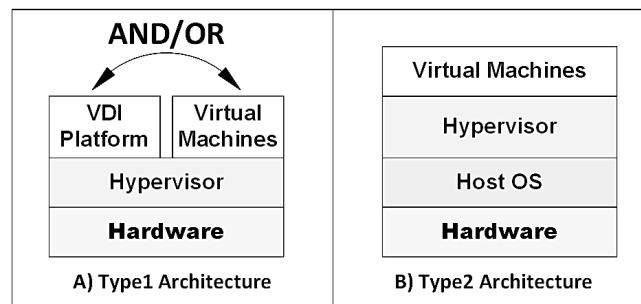
Figure 2.1: The Architecture Types of VDI Hypervisors

Virtualization is an alternative solution for effectively utilizing powerful physical machines. Upon adopting virtualization, many respective functions, which physical machine environments do not have, can be provided and exploited. For instance, two or more various operating systems can be concurrently running on the same hardware. Moreover, these operating systems, which are installed on different VMs, will be completely isolated from each other and they are called "guest operating systems".

From the implementation side, there are two architectures for applying virtualization; they are *Type1* and *Type2*. For Type 1, as shown in Figure 2.1 in the left part (A), the virtual environment can be implemented by using one of the various types of hypervisors running directly on hardware. The hypervisor is a special-purpose operating system by which VMs are created and running and it is the fundamental part for applying virtualization.

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.

However, Type 2 uses a general-purpose or full operating system as a foundation for its virtual environment. 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.

2.2   Virtual Machine Types

In general, hypervisors play a main role for creating and running VMs. Therefore they, particularly Type 1 hypervisors, can create and run either a pure VM directly, called "Virtual Machine", or a light virtual machine indirectly, called "Virtual Desktop". The VM can be directly running by the hypervisor itself without any platform in the middle whereas the VD can only be running using a VDI platform within a hypervisor. Moreover, the VM contains a fully-featured component while the VD contains an incomplete component in comparison with VM. For instance, the operating system must be installed in each VM while a set of VDs can be cloned to a single operating system called "Master Image", resulting in storage resource saving. On other hand, the VD end user does not have the full control and privileges as the VM end user does.

2.3   Virtual Machines Versus Virtual Desktops

2.3.1   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.

Type 1 Virtual Machines Architecture:

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
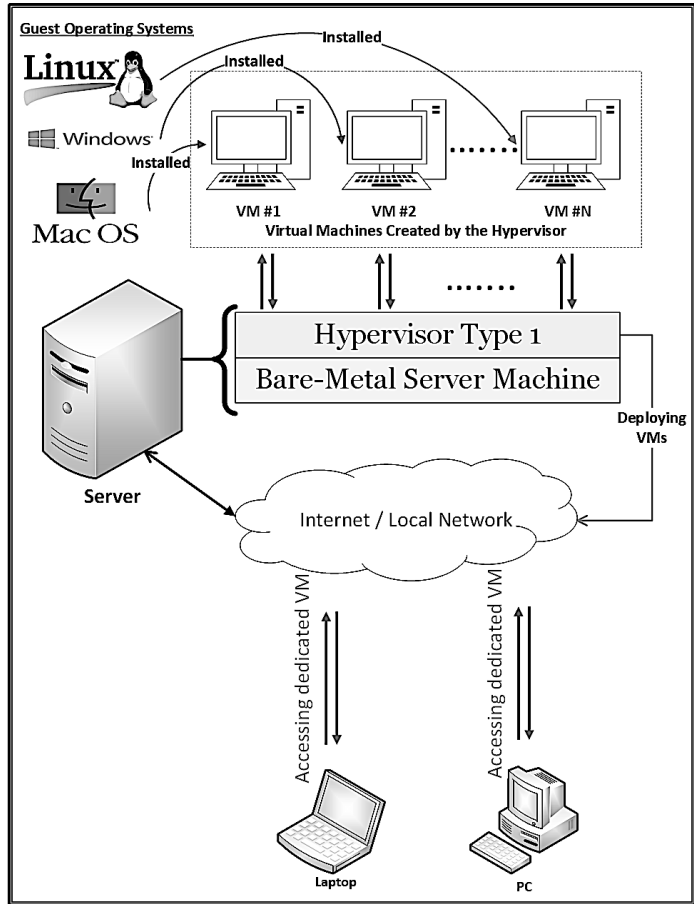
Figure 2.2: The Virtual Machines Architecture on Type 1 Hypervisor

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 2.2, 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.

Type 2 Virtual Machines Architecture:
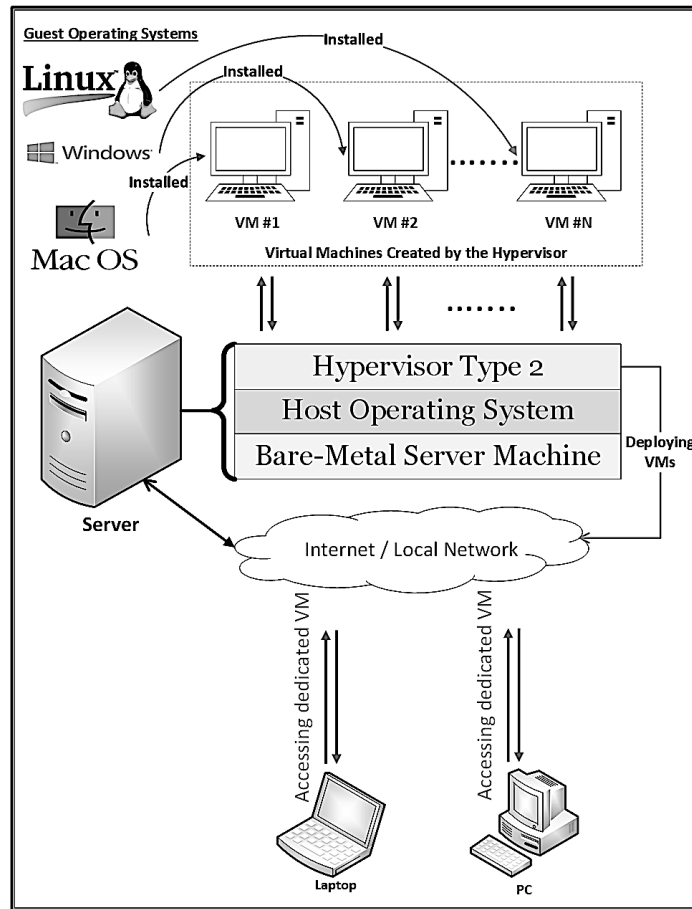
Figure 2.3: The Virtual Machines Architecture on Type 2 Hypervisor

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.

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As shown above in Figure 2.3, 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.

2.3.2   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 2.4 below.
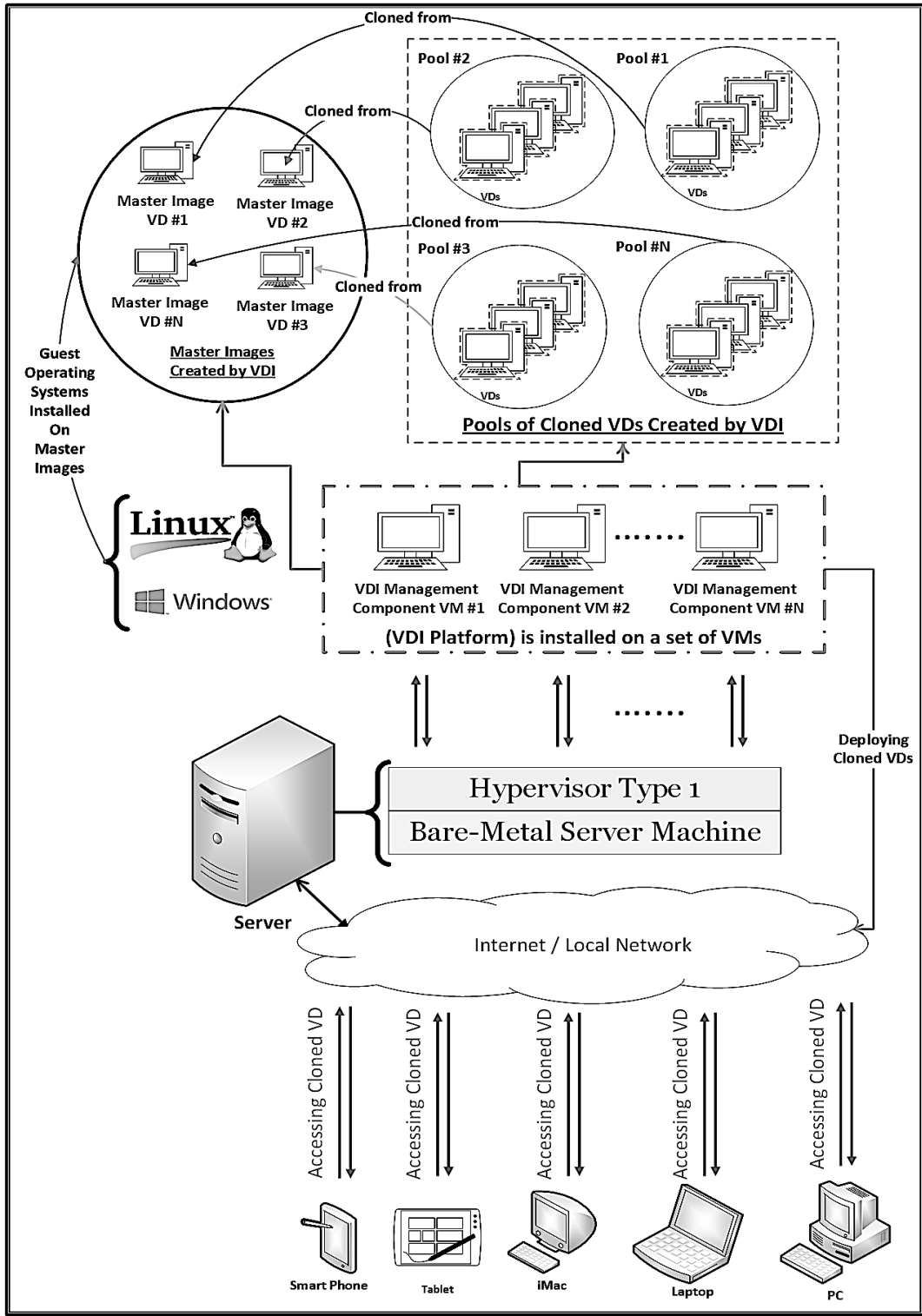
Figure 2.4: Virtual Desktops Architecture

2.4 *Login VSI* as a Benchmarking Software Tool

As stated in [1], "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.

CHAPTER 3

RELATED WORK

3.1   Overview

The papers in the references section have been surveyed in order to investigate into the experiments conducted. A variety of hypervisors and VDI platforms used for providing VD environments are produced by top market venders. The implementation of the experiments has been evaluated in terms of the architecture type of the hypervisor as well as the nature of the experimental environments whether they are homogeneous or heterogeneous. Also, the various products of the software hypervisors and VDI platforms have precisely been taken into consideration.

Tables 3.1 and 3.2 show the important remarks as well as the most significant elements of all the papers being reviewed. However, some of the reviewed papers do not specify the underlying experiments and some other papers do not have also any evaluation tests although their experiments have been implemented. Some papers as in [14], [18], [19] and [22] are just informative rather than experimental.

3.2 Various VDI Platforms Used

3.2.1 Evaluated VDIs

The authors of paper [3] 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 vender. 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.

The authors of paper [4] 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. In addition, the experiments conducted in this paper are all considered homogeneous. 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.

The authors of paper [15] have used a XenDesktop VDI platform on a XenServer hypervisor from the Citrix vender for their experiments and also a Horizon VDI platform on a vSphere hypervisor from the VMware vender for their experiments. 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.

The authors of paper [6] have only used a Horizon VDI platform on a vSphere hypervisor from the VMware vender for their experiments. 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. The evaluation of their experiments have been done using a monitoring hardware tool (physical device) in terms of a standard power meter and the specific name of the tool is mentioned in the paper which is Dual Y IEC Splitter.

The authors of paper [7] have only used a Horizon VDI platform on a vSphere hypervisor from the VMware vender for their experiments. 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. The evaluation of their experiments have been done using the built-in monitoring software tool in the VMware vshpere hypervisor.

The authors of paper [12] have only used a Horizon VDI platform on a vSphere hypervisor from the VMware vender for their experiments. 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. The evaluation of their experiments have been done using a benchmarking software tool in terms of disk I/O workloads and the specific name of the tool is mentioned in the paper which is Open Source Oracle VDBench.

The authors of paper [20] have only used a Horizon VDI platform on a vSphere hypervisor from the VMware vender for their experiments. 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. The evaluation of their experiments have been done using a benchmarking software tool in terms of disk I/O workloads and the specific name of the tool is mentioned in the paper which is Open Source Oracle VDBench.

The authors of paper [2] have only used a Microsoft VDI platform on a Hyper-V hypervisor from the Microsoft vender 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.

3.2.2   Non-Evaluated VDIs

The authors of paper [8] 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 authors of paper [9] have only used a Horizon VDI platform on a vSphere hypervisor from the VMware vender for their experiments. 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.

The authors of paper [10] 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.

3.3 Other Virtual Environmental Platforms

3.3.1 Hypervisor Platforms

The authors of paper [5], however, have only concentrated on evaluating hypervisors rather than VDI platforms in their experiments. 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 [13], [16], [17] and [21], have not given any details about the types of hypervisors or the VDI platforms used.

3.3.2 Virtual Machine Platforms

The authors of paper [11] have 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.

3.4　Summary

In order to summarize the experiments carried out in the related work chapter, as shown in Table 3.1, it has been discovered that the total number of homogeneous experiments is twelve, (92%). The details of these experiments are seven experiments applying the VMware product, (59%), four experiments applying the Citrix product, (33%) and only one experiment applying the Microsoft product, (8%). On the other hand, only one experiment is partially heterogeneous in which it applied only the Citrix VDI platform product on top of the VMware hypervisor product, (8%). The figures 3.1 and 3.2 below illustrate the various types of the experiments conducted and the various types of the VDI platforms used.
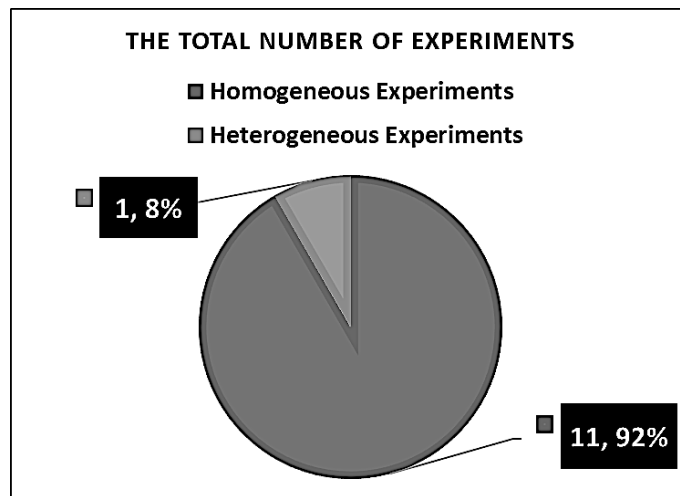
Figure 3.1: The Representation of the Homogeneous and Heterogeneous Experiments
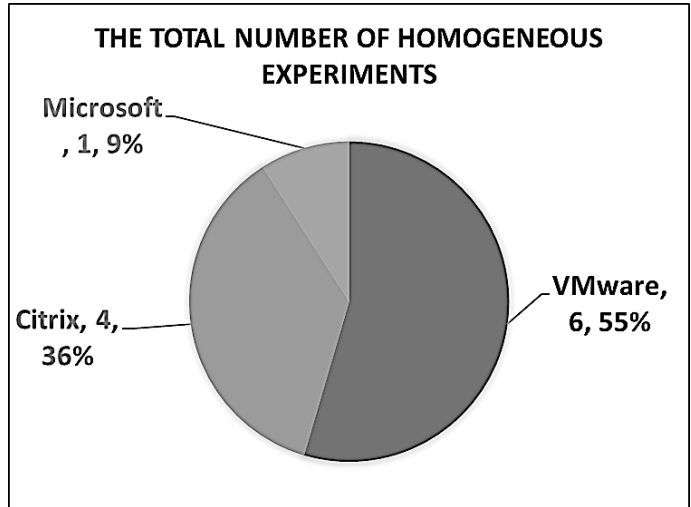
Figure 3.2: The Representation of the Various Homogeneous Experiments

Paper	Remarks	VDI Benchmarking Tool
[2]	*The hypervisor and VDI platform is* **homogeneous** *and only* **Microsoft products** *have been used*	[Network load monitoring, without specifying the exact name of the software tool]
[3]	*The hypervisor and VDI platform is* **homogeneous** *and only* **Citrix products** *have been used*	[Network emulator, the open-source software tool is called "wlinee"]
[4]	*The hypervisor and VDI platform is* **homogeneous** *and only* **Citrix products** *have been used*	[Network emulator, the open-source software tool is called "wlinee"]
[5]	*Only various hypervisors without VDI platforms*	[Irrelevant to VDI]
		Continued on the next page

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Paper	Remarks	VDI Benchmarking Tool
[6]	*The hypervisor and VDI platform is **homogeneous** and only **VMware products** have been used*	[A physical device of a standard power meter]
[7]	*The hypervisor and VDI platform is **homogeneous** and only **VMware products** have been used*	[The built-in monitoring software tool of the hypervisor]
[8]	*The hypervisor and VDI platform is **homogeneous** and only **Citrix products** have been used*	[No benchmarking software tool has been used]
[9]	*The hypervisor and VDI platform is **homogeneous** and only **VMware products** have been used*	[No benchmarking software tool has been used]
[10]	*Unspecified underlying hypervisors and specified VDI platforms [**Microsoft, Citrix and VMware**]*	[No benchmarking software tool has been used]
[11]	*Only VMs using only two operating systems [Windows and Linux] as both [guest and host] VMs, interchangeably*	[Irrelevant to VDI]

Paper	Remarks	VDI Benchmarking Tool
[12]	*The hypervisor and VDI platform is* **homogeneous** *and only* **VMware products** *have been used*	*Open Source Oracle VDBench*
[13]	*Unspecified*	*Devised VB Script*
[14]	*Informative without experiments*	*No benchmarking software tool has been used*
[15]	*The hypervisors and VDI platforms are* **homogeneous** *and* **heterogeneous***, and the* **Citrix, VMware products** *have been used*	*Microsoft Remote Desktop Load Simulation Tools and Login VSI*
[16]	*Unspecified*	*Devised VB Script*
[17]	*Unspecified*	*Designed Specific Network Protocol*
[18]	*Informative without experiments, only using VMware*	*No benchmarking software tool has been used*
[19]	*Informative without experiments, only using VMware*	*No benchmarking software tool has been used*
[20]	*The hypervisor and VDI platform is* **homogeneous** *and only* **VMware products** *have been used*	*Open Source Oracle VDBench*
	Continued on the next page	

Paper	Remarks	VDI Benchmarking Tool
[21]	*Unspecified*	*Microsoft Windows Performance Monitor*
[22]	*Informative without experiments*	*No benchmarking software tool has been used*

Table 3.1: The Important Remarks of the Selected Published Papers Reviewed

As shown in Figure 3.3 below, the benchmarking tools used in the experiments for all the papers are all software except one experiment which is the only hardware benchmarking tool. As noticed, the Login VSI software benchmarking tool is only used once in paper [15]. However, using Login VSI for once represents (8%) among other tools used in these experiments.
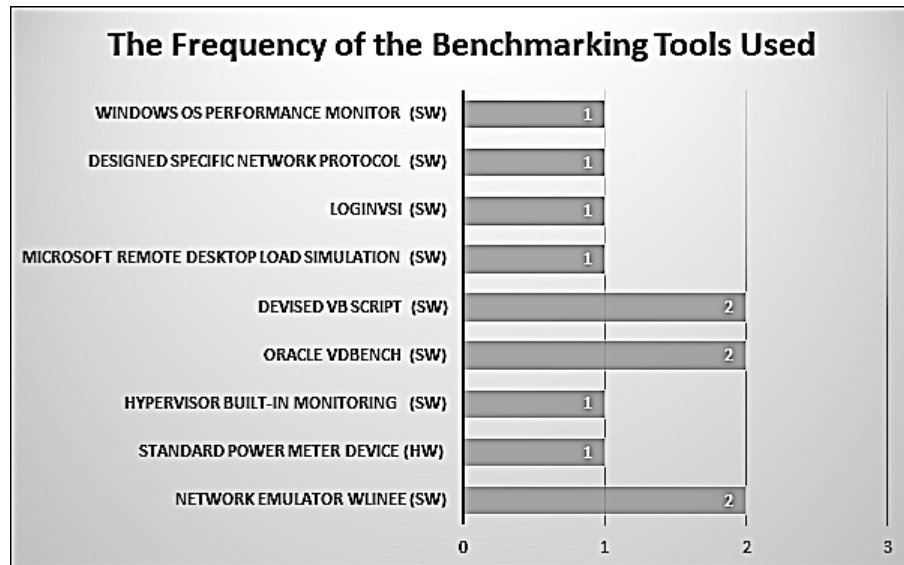
Figure 3.3: The Frequency of the Benchmarking Tools Used

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Paper	Architecture	Testing Type
[2]	Type 1	*VDI Performance Evaluation*
[3]	Type 1	*VDI Performance Evaluation*
[4]	Type 1	*VDI Performance Evaluation*
[5]	Type 1	*Only Hypervisors Cost and Performance Evaluation*
[6]	Type 1	*VDI Power Consumption Evaluation*
[7]	Type 1	*VDI Performance Evaluation*
[8]	Type 1	*VDI Usability [Cost Saving]*
[9]	Type 1	*VDI Usability [flexibility]*
[10]	Type 1	*No Evaluation*
[11]	Type 2	*VMs Performance Evaluation*
[12]	Type 1	*VDI Performance Evaluation*
[13]	Type 1	*Maximum VDs, Network Utilization and I/O Operations Per Second*
[14]	Nothing Used	*No Evaluation*
[15]	Type 1	*VDI Performance and Capacity Evaluation*
[16]	Type 1	*VDI Performance, Network and Audio Transmission Evaluation*
[17]	Type 1	*VDI Network Protocol Evaluation*
[18]	Type 1	*No Evaluation*
[19]	Type 1	*No Evaluation*
		Continued on the next page

Paper	Architecture	Testing Type
[20]	Type 1	*VDI Performance, Scalability and Reliability Evaluation*
[21]	Type 1	*VDI Performance Evaluation*
[22]	Nothing Used	*No Evaluation*

Table 3.2: The Main Elements of the Selected Published Papers from the Literature

In light of the above, all the architecture types of the experiments implemented in the reviewed papers are Type 1 except the papers [11], [14] and [22]. In regard to the testing types, almost nine papers have evaluated VDI in terms of performance while other papers have evaluated VDI in terms of either network utilization, network transmission, network protocol, audio transmission, I/O operations, usability or power consumption. However, there are some other papers which have no evaluations as in the papers [10], [14], [18], [19] and [22].

According the paper [15], it is the only paper which has evaluated VDI by using the Login VSI as a software benchmarking tool that this thesis is going to use. As seen in the paper, it has implemented three experiments, two of which are homogeneous and the third one is heterogeneous. The evaluation has overlooked considering the impact of inter-arrival time of VDs on the results of a test as a factor for evaluation. Also, the experiments have a lack of a confidence level on the results since the authors did not have multiple runs for their experiments in order to get reliable results. In this thesis, the missing factor as well as increasing the level of confidence on the results will be considered in order to fill in the gap.

CHAPTER 4

PROPOSED METHODOLOGY

4.1 VDI Methodology Architecture

It should be known that the layers needed for any VDI environment to be tested are shown below in 4.1. They are composed of a layer of a server hardware, a layer of a hypervisor and a layer of virtual machines. The VDI platform must be installed in one or a set of virtual machines forming the VDI environment and the Login VSI benchmarking tool must be too. For this reason, the virtual machines running on the layer of hypervisor are necessary to exist as a base for the VDI environment itself as well as the Login VSI benchmarking tool although the latter can be also used and running in separate physical machines as an alternative way from using virtual machines. Although the whole VDI environment is built on top of virtual machines, it will produce eventually virtual desktops as an outcome rather than new other virtual machines.
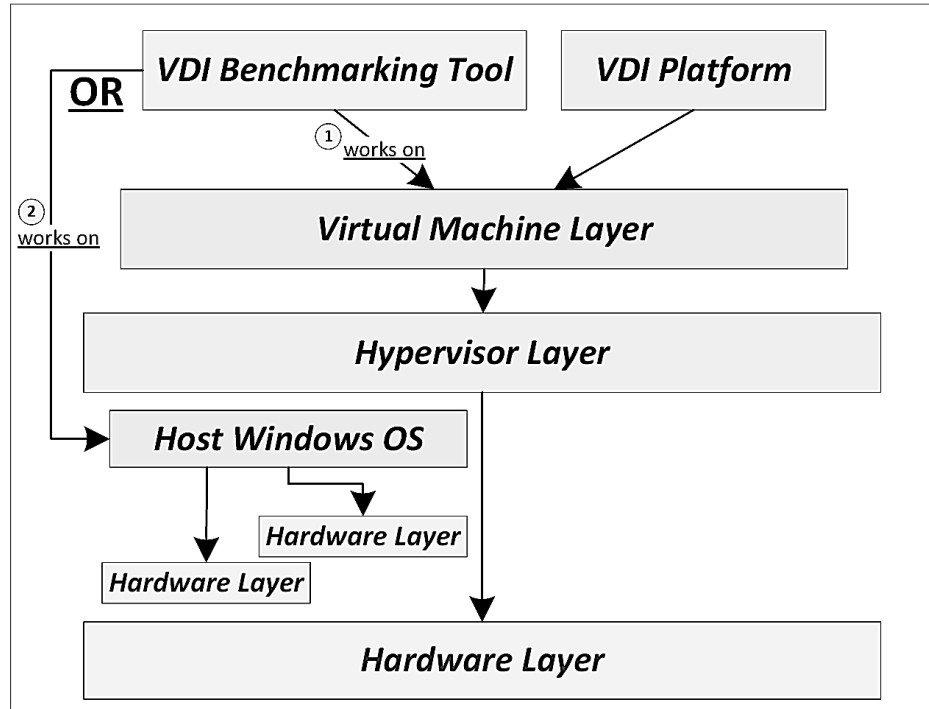
Figure 4.1: The Architecture of the Required Layers for the Experiments

4.2 Login Virtual Session Indexer (Login VSI)

4.2.1 Login VSI Architecture

The Login VSI benchmarkring software tool is composed of two main compo-
nents for tests. They are Login VSI Management Console (MMC) and Login VSI
Launcher. The performance monitoring of experiments cannot be accomplished
unless both are together used in tests. In addition, Login VSI Analyzer is another
component for automatically analyzing results collected by MMC. The MMC is
a console platform where a VDI evaluator is able to configure a test to their tar-
get VDI environment. The Launcher is the component that is responsible for
launching virtual desktops in every certain time during which the test is running
as configured. All Login VSI main components must be installed in separate ma-

chines. Furthermore, both must be parts of an active directory and join to the domain.
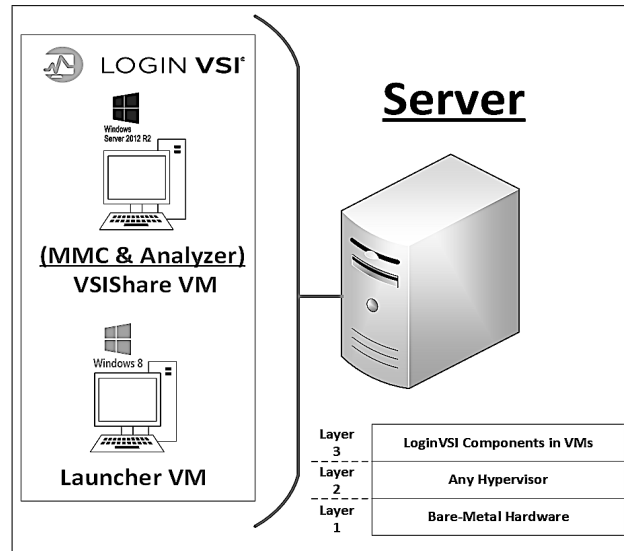
Figure 4.2: The Architecture of the Login VSI Benchmarking Software Tool

4.2.2 Login VSI Selected Types of Predefined Workloads

Login VSI has a set of standard predefined workloads although a customized workload can be constructed by the user. The Login VSI predefined workloads are Task Worker, Office Worker, Knowledge Worker and Power Worker. Only two particular workloads have been selected among others for the performance evaluation in the thesis VDI environments which are the lightest predefined workload (Task Worker) and the heaviest predefined workload (Power Worker).

The reasons of these specific choices are to get a fair assessment about the top market VDI products used at the present time. Also, since the aim is to apply a VDI platform in an educational environment, our computer science VDI model designed before has especially been used as a narrow scope and a standard for the

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courses in this major which can be also easily generalized in other subjects. The computer science courses are divided into two main groups. These groups are a light course group and a heavy course group.

The light course group is defined as a course needs to use a few desktop applications consuming minimum vCPUs processors as possible while the heavy course group is defined as a course needs to use several desktop applications consuming fair enough vCPUs processors. Therefore, courses should be previously evaluated and categorized under their corresponding group by the major coordinator along with faculty members who are going to teach those courses. As a result, two lists of courses should be filled in these groups. The courses in the light course group will be given the Login VSI predefined workload, (Task Worker). On the other side, the courses in the heavy course group will be given the Login VSI predefined workload, (Power Worker).

As shown in Table 4.1, the predefined light workload will use at least two desktop applications as minimum and at most seven desktop applications as maximum. The types of desktop applications used in this particular workload is identified in Table 4.2. The minimum hardware requirements to operate this workload successfully are (1 vCPU) and (1 GB of RAM). However, the predefined heavy workload will use at least eight desktop applications as minimum and at most twelve desktop applications as maximum. The types of desktop applications used in this particular workload is identified in Table 4.2. The minimum hardware requirements to operate this workload successfully are (2 vCPUs) and (2 GB of RAM).

There are main differences between these specific predefined workloads in terms of CPU utilization and reading or writing from/to the disk. The CPU operations in the light workload will consume up to 70% of the total 1 vCPU processor whereas the CPU operations in the heavy workload will consume up to 119% of the total 2 vCPUs processors, (consuming up to 100% from one vCPU and 19% remaining from the other vCPU or 60% of each vCPU if they are equally divided). The ratio of CPU utilization between these workloads is **70%** difference. For the disk operations, the ratio between these workloads is about **80%** difference.

Workload Name / Type	Application Opened	Estimated CPU Usage	Estimated IOPS Per User	Typical VM Memory Profile	Typical VM vCPU Profile
(Light) Task Worker	2-7	70%	6.0	1.0 GB	1vCPU
(Heavy) Power Worker	8-12	119%	10.8	2.0 GB	2vCPU+

Table 4.1: The Configurations and Utilizations of Computing Resources for Login VSI Workload Types

A set of desktop applications can be used in the different workloads. These applications can be writing documents in MS Word, calculating numbers in MS Excel, writing emails in MS Outlook, preparing presentations in MS PowerPoint, reading PDF files in Adobe Reader, surfing web pages in Internet Explorer, Drawing in Java, Compressing files in Zip7, watching videos within browsers, viewing images or installing fake applications as specified in Table 4.2 below.

Desktop Application Type	Task Worker	Power Worker
Microsoft Word 2016	☑	☑
Microsoft Excel 2016	☑	☑
Microsoft Outlook 2016	☑	☑
Microsoft PowerPoint 2016	☒	☑
Internet Explorer	☑	☑
Adobe Reader DC / Dore PDF	☑	☑
Freemind / Java	☒	☑
Photo Viewer / Adobe Flash	☒	☑
Compressing Files	☑	☑
Notepad	☑	☑
Simulated Application Install	☒	☑
Launching Videos into Browser	☒	☑
Applications Total Number	**7**	**12**

Table 4.2: The Specific Applications Opened of the Predefined Workload Types

4.2.3   Login VSI Test Description

The test is configured based on VDI evaluator's desire through Login VSI MMC. The test is going to execute the same workloads in all sessions equally which are configured and launched incrementally plus two minutes as a default time for logging off the running sessions sequentially in a way of FIFO. The objective of the test is to push the performance to the limit (VSImax Threshold) which has been formulated as (Baseline + 1000 ms latency). Once the total response time of all the sessions running during a test has reached the VSImax Threshold, then the system is saturated and the maximum capacity of the environment that can handle will be precisely calculated. As the example shown below in Figure 4.3, the total duration time of Login VSI test is twenty four minutes for capturing performance in response time. The inter-arrival time of launching each session will be constant which is two minutes and twenty four seconds calculated by MMC.

The test is started by the first session VD#1 in the first second of the test. The VD#1 will start executing its workload. When the inter-arrival time of VD#2 has come, the VD#2 will be launched and the execution of its workload will be started along with VD#1. The same process will continue for VD#3,4,5,6,7,8,9 and 10. Eventually, ten sessions will be typically running and executing their workloads separately. There will be only two cases for the result of the test. The first case is that the VSImax Threshold is not reached. Then, the maximum number of the virtual desktops is going to be the same as the number of configured sessions for test if and only if there are no stuck or inactive sessions as a total capacity. However, the second case is that the VSImax Threshold is reached. Then, the maximum number of the virtual desktops is going to be less than the number of configured sessions for test although there may be no stuck or inactive sessions.
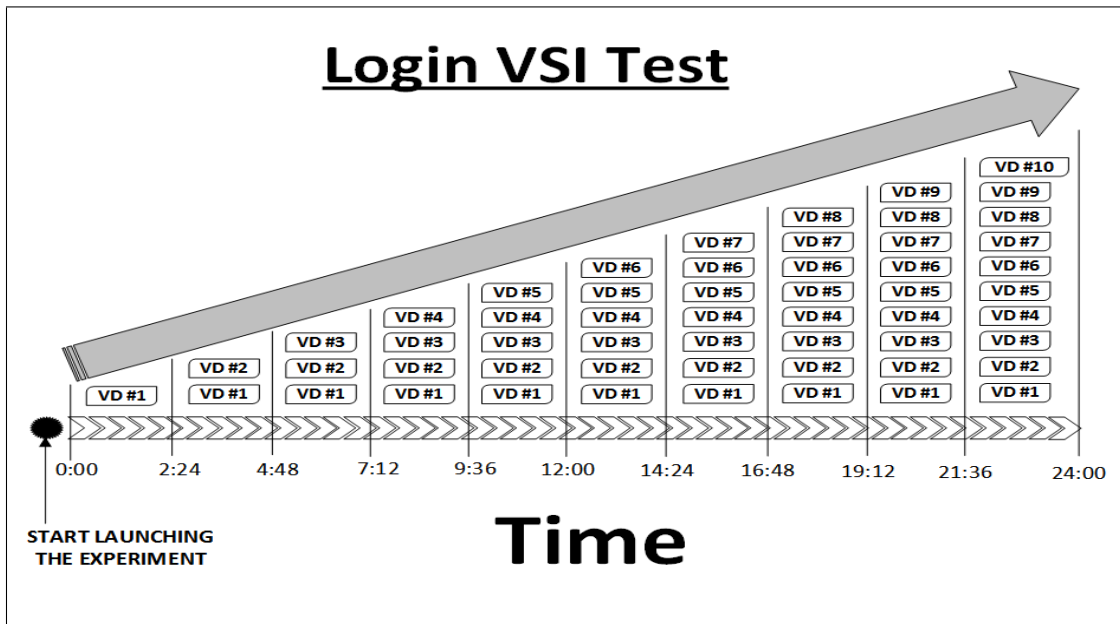
Figure 4.3: The Login VSI Work of Running 10 Virtual Desktops

4.3   Experimental Design

4.3.1   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 five. 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 4.4 below.
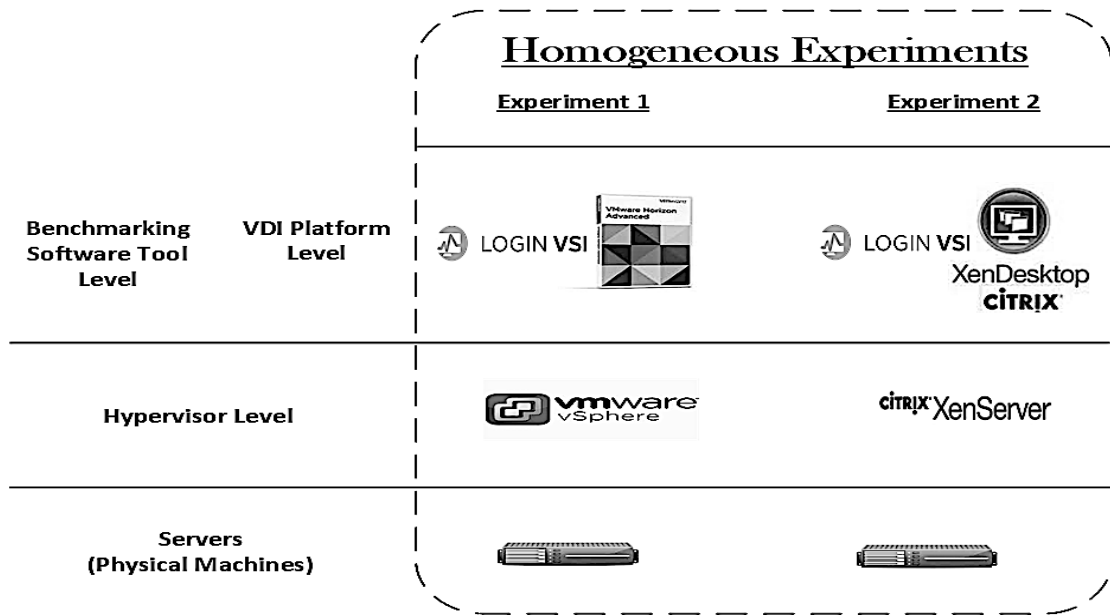
Figure 4.4: The Abstract Levels of the Experimental Design

4.3.2   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.

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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	2.5 Minutes	50 Minutes

Table 4.3: The General Parameters of the 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

Table 4.4: The Total Number of Systematic Experiments

4.3.3 Experimental Infrastructure

Hardware Specifications

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 4.5: The Hardware Specifications of the Five Servers

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 4.5 above describes the hardware specifications of the five servers used.

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Software Specifications

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

Table 4.6: The Software Specifications Installed on the Five Servers

In Table 4.6 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.

4.4 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 most suitable one to use within 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

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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.

4.5   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 as stated in Tables 5.4 and 5.11. 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.

CHAPTER 5

EXPERIMENTS AND

RESULTS

5.1   Evaluation Environment Scope

Figure 5.1 below illustrates the scope of our evaluation environment. The Figure shows the different Cloud Models including SaaS, DaaS, PaaS, and IaaS. The work carried out in this thesis fits under DaaS since we are proposing the usage of virtual desktops in an educational environment. Two flavors of creating virtual desktops are being used so far. They are Full Clone (Dedicated) and Linked Clone Virtual Desktops.

Only one has been selected for the performance evaluation which is the Linked-Clone virtual desktop. The main reason for choosing is that for educational purpose, there is a strong need for utilizing universities' computing resources as much as possible and minimizing efforts and time as fast as possible when important

changes and updates have to be made. Also, Floating Assignment is only being considered. It means that the user's profile is totally separate form a virtual desktop and it will be attached with any available empty VD from a certain pool at a time the user accesses their VD and all the user's desktop applications and files are going to be stored specifically in their profile instead of the VD itself. This will make the minimum storage capacity given initially to the user grows gradually as long as the user continuously needs that along the time leading to utilizing the storage hardware resource effectively. Finally, the operating system version used for VDs is Windows 7 as a software platform while a hard drive disk is only used as a type of storage device for the thesis experiments due to hardware limitation.
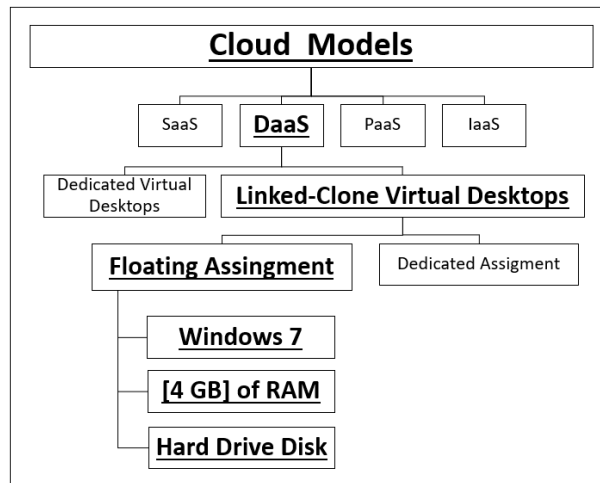
Figure 5.1: The Scope of the Experiments.

In summary, the following experiments have been conducted based on three main factors as mentioned in Table 5.1 below. Theses factors are the configured maximum number of VDs for each test, the type of the workload used and the inter-arrival time every session will log in to a test. Thus, from these three factors,

five experiments can be configured as total for each VDI platform. As a result, ten experiments have been conducted for both VDI environments, (VMware and Citrix). Also, every experiment are repeated three times as three runs.

	E1	E2	E3	E4	E5
10 - Virtual Desktops	✓	✓	✓	✓	
20 - Virtual Desktops					✓
Light Workload	✓		✓		✓
Heavy Workload		✓		✓	
Inter-Arrival Time - 2.5M	✓	✓			✓
Inter-Arrival Time - 5.0M			✓	✓	

Table 5.1: The Different Factors of Experiments

5.2   Performance Evaluation Metrics

1. **VSImax Baseline or Baseline**

Range	Baseline Rating
0 - 799	Very Good
800 - 1199	Good
1200 - 1599	Fair
1600 - 1999	Poor
2000 - 9999	Very Poor

Table 5.2: The Baseline Performance Rating. Adopted from [1].

It must be known that the specific meaning of the Baseline in the context here is *(Performance of the System without Stress)*. Also, the rating of Baseline above in Table 5.2 is based on different ranges of response times in milliseconds. Moreover, the Baseline rating is specified and coming from the Login VSI documentation [1].

As stated in [1], the VSImax Baseline or Baseline is calculated as follows:

"15 lowest VSI response time samples are taken from the entire test, the

lowest 2 samples are removed and the 13 remaining samples are averaged. The result is the Baseline.". In addition, the Login VSI Analyzer as a software tool is used for calculating the Baseline of a test automatically. The most important point about the Baseline is that the lower the Baseline score is the better. The aim of Baseline is to find out the best performance for various systems that have variant hardware specifications and get a good indication of the results obtained in order to evaluate between different systems. Also, it is helpful to determine the threshold where the performance will start in degradation.

2. ***The Maximum Number of Successful Virtual Desktops Running in the VDI Environment (VSImax).***

Referring to [1], the system is called "Saturated" when the threshold of the total response time has been reached. The saturation point is calculated by the Baseline response time measured in ms added to 1000 ms latency which is equal to one second the user can clearly feel such delay in response time. The successful virtual desktops are only counted when they are being active as well as a session or more must not get in a stuck state during a test. More specifically, the maximum number of the virtual desktops (sessions) the VDI environment can handle as a maximum capacity is the virtual desktops which successfully complete executing their workloads before the saturation point is reached in a test.

5.3   VMware Homogeneous Experiment

5.3.1   VMware-Experiment Architecture and Description

The architecture of VMware Experiment consists of three separate servers. The first server, named Server #5 as shown in Figure 5.2, should contain three virtual machines. The first virtual machine will be used as an active directory. The other two virtual machines will be used for the Login VSI benchmarking software tool (Dataserver and Launcher). They have already been explained in Chapter 2. The other two servers will be used for the VMware VDI environment, named Server #1 and Server #2, as shown in Figure 5.2. Server #1 has the management components of the VMware VDI product called (VMware Horizon), while Server #2 will contain only the virtual desktops running on it and created by VMware Horzion installed on Server #1 so that no other factor except the hypervisor on which VDs reside will affect the results.

Three main components must be installed in separate virtual machines on Server #1 in order to make VMware Horizon successfully running. They are VMware View Connection, View Center and View Composer. In the VMware View Connection VM, pools of VDs can be configured either created, deleted or updated. When only pools of Linked-clone VDs are chosen to be created, then the VMware Composer VM is necessary to use. Finally, the View Center VM is the actual component that receives requests form the View Connection VM and processes the implementation of all operations on pools of VDs in Server #2 according to the View Connection specific operational requests.
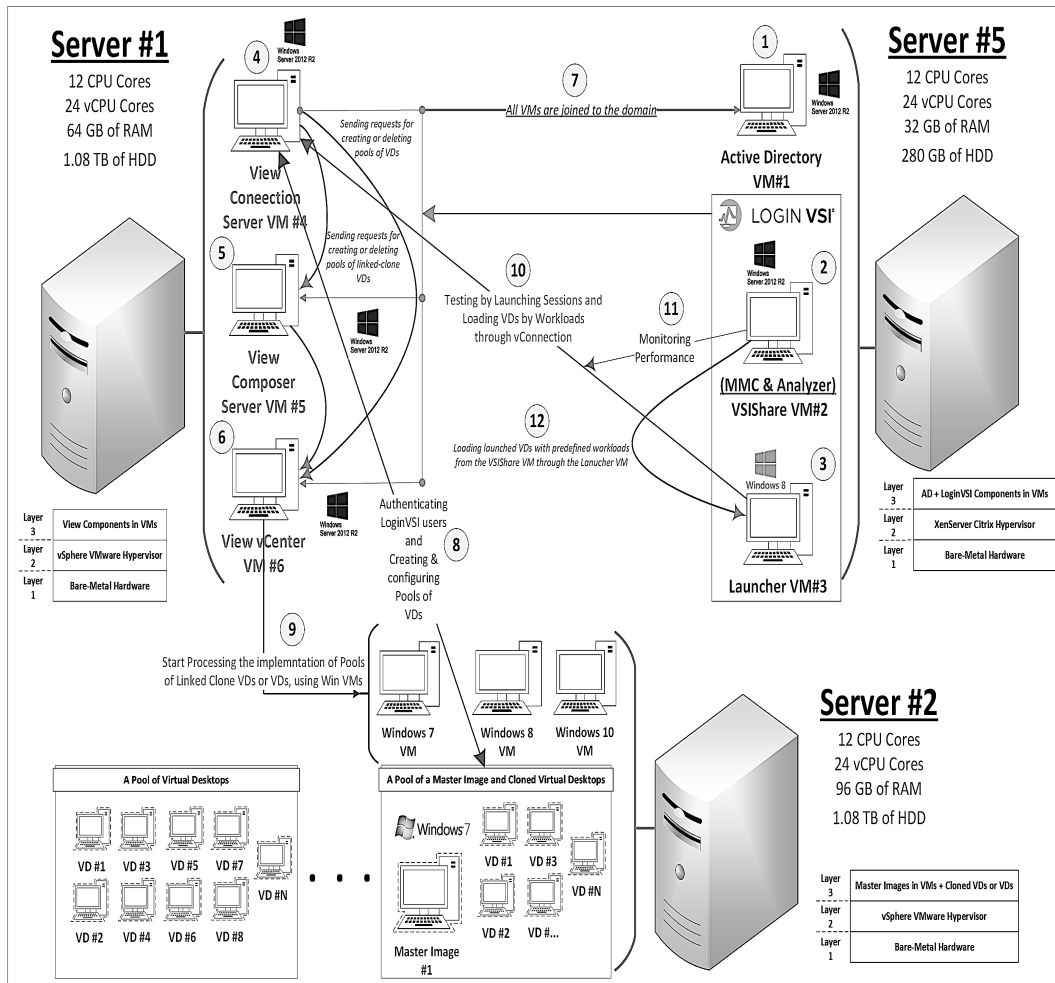
Figure 5.2: The Architecture of the VMware Experiment

5.3.2   VMware-Experiment HW/SW Specifications

As an infrastructure for the experimental environment, the hardware specifications used in the three servers are generally identical except the main memory size and the storage capacity as mentioned below in Table 5.3. However, Table 5.4 shows in general all the main software components installed for preparation of conducting experiments. The main reason of this table is to know exactly which versions have been used for each software component and where they are located.

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

Table 5.3: The Hardware Specifications of the Three Servers for VMware Experiment

Architecture Level	Software	Version	Installed Location
Hypervisor	VMware vSphere	6.5	Servers: #1 and 2
	Citrix XenServer	7.0	Server #5
VDI platform	VMware Horizon	7.0	Server #1
Administrating Tool	vSphere Client	6.5	Administrator Machine
Administrating Tool	XenCenter Client	7.0	Administrator Machine
Benchmarking Tool	Login VSI	4.1	Server #5
Virtual Machine	Operating System	Win S2012	Servers: #1 and 5
		Win 8	Server #5
		Win 7	Server #2

Table 5.4: The Software Specifications Installed on the Three Servers

5.3.3 Collected Results of VMware VDI Platform

The results of the following five experiments will be presented into a few runs, (Three Runs). These runs are categorized as Best, Average (AVG) and Worst. Once the results of all runs have been collected, they have been directly categorized based on the maximum number of successful virtual desktops (VSImax) reached, the Baseline score and then VSImax Average (only looked at if the VSImax and Baseline are exactly equal). Specifically, the higher the capacity number reached of virtual desktops (VSImax) in the VDI environment is the better. On the other hand, the lower the Baseline score as well as VSImax Average score is the better.

For the following tables from Table [5.5] to Table [5.9], there are main parameters should be explained in detail to well understand the results contained. The test time duration is the total time of the complete test including the logging off default time (2 minutes). The inter-arrival time is the period of time where every new session can regularly access the test and it is calculated automatically by Login VSI MMC using the formula (test duration, excluding logging in default time, divided by configured VDs for test). The version of operating system and the type of workload have been specifically used. In addition, the total number of virtual desktops can be tested as maximum in the configured sessions for test.

In the results, the successful completed session is the session which has finished executing its workload successfully during the test. The unlaunched session is the session that is not able to log in and access the test. The inactive session is the session where it is launched successfully but it cannot enter the test for some hidden reason. The active session, however, can be launched and enter the test successfully. The stuck session is anything that prevents the session from executing its workload completely and successfully while it is active. However, the other parameters have been previously mentioned and explained.

- **VMware Experiment #1** [**10-VDs, Task-Worker, 2.5-Minutes**]

As stated below in Table 5.5, the Baselines of these light-workload runs have ranged from [1261 ms as minimum and 1281 ms as maximum] by *20 ms* span. They all have the same Login VSI rating, which is *Fair*. Also, it must me noted that the saturation point for each run has not been reached. The reason is that the

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VSImax Threshold of each run has not been reached at any time even when the maximum ten sessions were running during the whole test period of 2.5 minutes inter-arrival time.

[VMware, 1-vCPU, 4GB-RAM]	Best-Run	AVG-Run	Worst-Run
Test Time Duration	(1440 Seconds = 24 Minutes) + 2 Minutes		
Inter-Arrival Time	Sessions logged in every 144 Seconds		
Operating System Version	Microsoft Windows 7		
Workload Type	Light (Task Worker)		
Configured Sessions for Test	(10) Virtual Desktops / Sessions		
Successful Completed Sessions	10	10	10
Unlaunched Sessions	0	0	0
Inactive Sessions	0	0	0
Stuck Sessions	0	0	0
Active Sessions	10	10	10
Performance Baseline(Rating)	1261 ms (Fair)	1262 ms (Fair)	1281 ms (Fair)
VSImax Index Average	1292 ms	1344 ms	1336 ms
VSImax Threshold	2261 ms	2262 ms	2281 ms
System Saturation	Not Reached	Not Reached	Not Reached

Table 5.5: The Collected Results of VMware Experiment 1

As shown below in Figure 5.3, it is very obvious to observe that all light-workload runs have achieved **100%** of the maximum capacity of the 10-virtual-desktops test, which is [*10 VDs*]. In addition, the differences between every run from the other two runs are **0%**.

However, only the average run of experiment #1 is going to be discussed and taken into consideration in comparison with the similar Cirix experiment in Section 5.5.3. This specific run has been selected among others to avoid bias as much as possible and exclude outliers in sampling by only choosing the average sample between the three runs.

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Figure 5.3: The Percentages of VMware Runs of E1.

• **VMware Experiment #2** [**10-VDs, Power-Worker, 2.5-Minutes**]

As stated below in Table 5.6, the Baselines of these heavy-workload runs have ranged from [946 ms as minimum and 965 ms as maximum] by *19 ms* span. They all have the same Login VSI rating, which is *Good*. Also, it must me noted that the saturation point for each run has not been reached. The reason is that the VSImax Threshold of each run has not been reached at any time even when the maximum ten sessions were running during the whole test period of 2.5 minutes inter-arrival time.

[VMware, 2-vCPU, 4GB-RAM]	Best-Run	AVG-Run	Worst-Run
Test Time Duration	(1440 Seconds = 24 Minutes) + 2 Minutes		
Inter-Arrival Time	Sessions logged in every 144 Seconds		
Operating System Version	Microsoft Windows 7		
Workload Type	Heavy (Power Worker)		
Configured Sessions for Test	(10) Virtual Desktops / Sessions		
Successful Completed Sessions	10	10	10
Unlaunched Sessions	0	0	0
Inactive Sessions	0	0	0
Stuck Sessions	0	0	0
Active Sessions	10	10	10
Performance Baseline(Rating)	946 ms (Good)	949 ms (Good)	965 ms (Good)
VSImax Index Average	985 ms	1009 ms	1024 ms
VSImax Threshold	1946 ms	1949 ms	1965 ms
System Saturation	Not Reached	Not Reached	Not Reached

Table 5.6: The Collected Results of VMware Experiment 2

As shown below in Figure 5.4, it is very obvious to observe that all heavy-workload runs have achieved **100%** of the maximum capacity of the 10-virtual-desktops test, which is [*10 VDs*]. In addition, the differences between every run from the other two runs are **0%**.

However, only the average run of experiment #2 is going to be discussed and taken into consideration in comparison with the similar Cirix experiment in Section 5.5.4. This specific run has been selected among others to avoid bias as much as possible and exclude outliers in sampling by only choosing the average sample between the three runs.
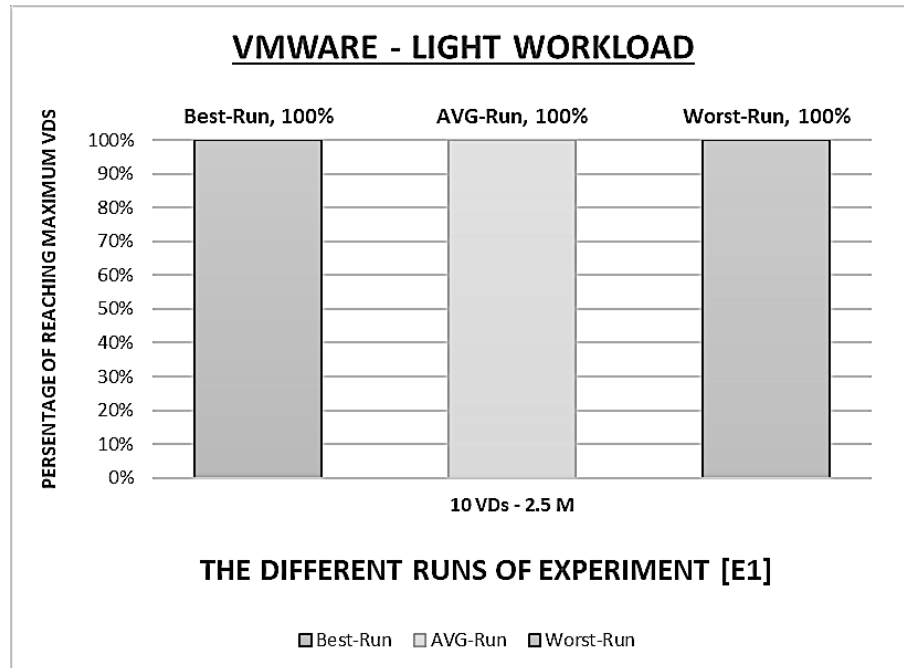
Figure 5.4: The Percentages of VMware Runs of E2.

- **<u>VMware Experiment #3</u> [10-VDs, Task-Worker, 5.0-Minutes]**

As stated below in Table 5.7, the Baselines of these light-workload runs have ranged from [1223 ms as minimum and 1240 ms as maximum] by *17 ms* span. They all have the same Login VSI rating, which is *Fair*. Also, it must me noted that the saturation point for each run has not been reached. The reason is that the VSImax Threshold of each run has not been reached at any time even when the maximum ten sessions were running during the whole test period of 5.0 minutes inter-arrival time.

[VMware, 1-vCPU, 4GB-RAM]	Best-Run	AVG-Run	Worst-Run
Test Time Duration	(2880 Seconds = 48 Minutes) + 2 Minutes		
Inter-Arrival Time	Sessions logged in every 288 Seconds		
Operating System Version	Microsoft Windows 7		
Workload Type	Light (Task Worker)		
Configured Sessions for Test	(10) Virtual Desktops / Sessions		
Successful Completed Sessions	10	10	10
Unlaunched Sessions	0	0	0
Inactive Sessions	0	0	0
Stuck Sessions	0	0	0
Active Sessions	10	10	10
Performance Baseline(Rating)	1223 ms (Fair)	1232 (Fair)	1240 ms (Fair)
VSImax Index Average	1286 ms	1373	1460 ms
VSImax Threshold	2223 ms	2232	2240 ms
System Saturation	Not Reached	Not Reached	Not Reached

Table 5.7: The Collected Results of VMware Experiment 3

As shown below in Figure 5.5, it is very obvious to observe that all light-workload runs have achieved **100%** of the maximum capacity of the 10-virtual-desktops test, which is [*10 VDs*]. In addition, the differences between every run from the other two runs are **0%**.

However, only the average run of experiment #3 is going to be discussed and taken into consideration in comparison with the similar Cirix experiment in Section 5.5.3. This specific run has been selected among others to avoid bias as much as possible and exclude outliers in sampling by only choosing the average sample between the three runs.
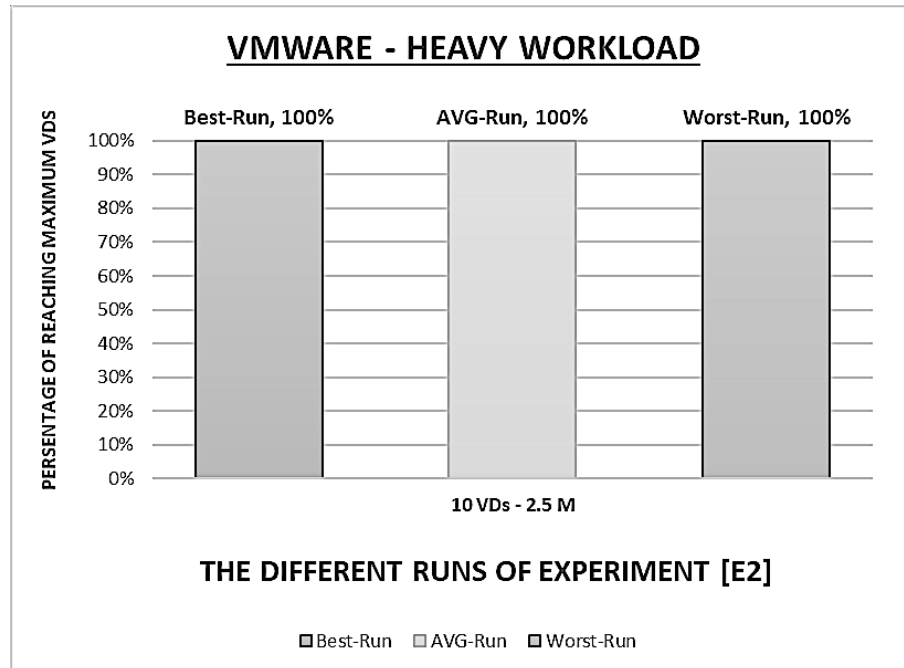
VMWARE - LIGHT WORKLOAD

Figure 5.5: The Percentages of VMware Runs of E3.

- **VMware Experiment #4** [**10-VDs, Power-Worker, 5.0-Minutes**]

As stated below in Table 5.8, the Baselines of these heavy-workload runs have ranged from [969 ms as minimum and 1003 ms as maximum] by *34 ms* span. They all have the same Login VSI rating, which is *Good*. Also, it must me noted that the saturation point for each run has not been reached. The reason is that the VSImax Threshold of each run has not been reached at any time even when the maximum ten sessions were running during the whole test period of 5.0 minutes inter-arrival time.

[VMware, 2-vCPU, 4GB-RAM]	Best-Run	AVG-Run	Worst-Run
Test Time Duration	(2880 Seconds = 48 Minutes) + 2 Minutes		
Inter-Arrival Time	Sessions logged in every 288 Seconds		
Operating System Version	Microsoft Windows 7		
Workload Type	Heavy (Power Worker)		
Configured Sessions for Test	(10) Virtual Desktops / Sessions		
Successful Completed Sessions	10	10	10
Unlaunched Sessions	0	0	0
Inactive Sessions	0	0	0
Stuck Sessions	0	0	0
Active Sessions	10	10	10
Performance Baseline(Rating)	969 (Good)	982 ms (Good)	1003 ms (Good)
VSImax Index Average	1023 ms	998 ms	976 ms
VSImax Threshold	1969 ms	1982 ms	2003 ms
System Saturation	Not Reached	Not Reached	Not Reached

Table 5.8: The Collected Results of VMware Experiment 4

As shown below in Figure 5.6, it is very obvious to observe that all heavy-workload runs have achieved **100%** of the maximum capacity of the 10-virtual-desktops test, which is [*10 VDs*]. In addition, the differences between every run from the other two runs are **0%**.

However, only the average run of experiment #4 is going to be discussed and taken into consideration in comparison with the similar Cirix experiment in Section 5.5.4. This specific run has been selected among others to avoid bias as much as possible and exclude outliers in sampling by only choosing the average sample between the three runs.
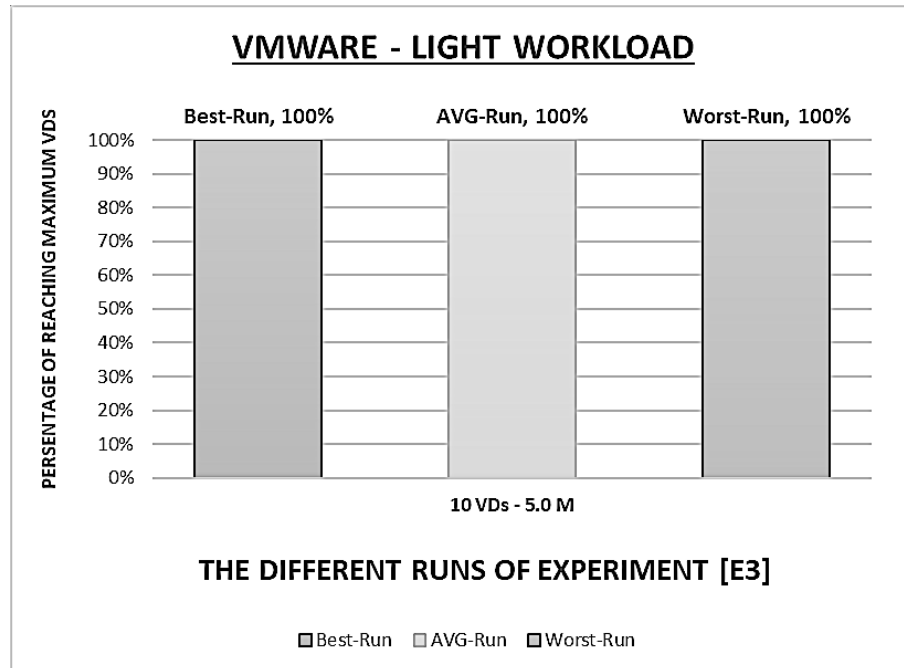
Figure 5.6: The Percentages of VMware Runs of E4.

- **VMware Experiment #5** [**20-VDs, Task-Worker, 2.5-Minutes**]

As stated below in Table 5.9, the Baselines of these light-workload runs have ranged from [1299 ms as minimum and 1305 ms as maximum] by *6 ms* span. They all have the same Login VSI rating, which is *Fair*. Also, it must me noted that the saturation point for each run has not been reached. The reason is that the VSImax Threshold of each run has not been reached at any time even when the maximum twenty sessions were running during the whole test period of 2.5 minutes inter-arrival time.

[VMware, 1-vCPU, 4GB-RAM]	Best-Run	AVG-Run	Worst-Run
Test Time Duration	(2880 Seconds = 48 Minutes) + 2 Minutes		
Inter-Arrival Time	Sessions logged in every 144 Seconds		
Operating System Version	Microsoft Windows 7		
Workload Type	Light (Task Worker)		
Configured Sessions for Test	(20) Virtual Desktops / Sessions		
Successful Completed Sessions	20	20	20
Unlaunched Sessions	0	0	0
Inactive Sessions	0	0	0
Stuck Sessions	0	0	0
Active Sessions	20	20	20
Performance Baseline(Rating)	1299 ms (Fair)	1299 ms (Fair)	1305 ms (Fair)
VSImax Index Average	1376 ms	1421 ms	1412 ms
VSImax Threshold	2299 ms	2299 ms	2305 ms
System Saturation	Not Reached	Not Reached	Not Reached

Table 5.9: The Collected Results of VMware Experiment 5

As shown below in Figure 5.7, it is very obvious to observe that all light-workload runs have achieved **100%** of the maximum capacity of the 20-virtual-desktops test, which is [*20 VDs*]. In addition, the differences between every run from the other two runs are **0%**.

However, only the average run of experiment #5 is going to be discussed and taken into consideration in comparison with the similar Cirix experiment in Section 5.5.3. This specific run has been selected among others to avoid bias as much as possible and exclude outliers in sampling by only choosing the average sample between the three runs.
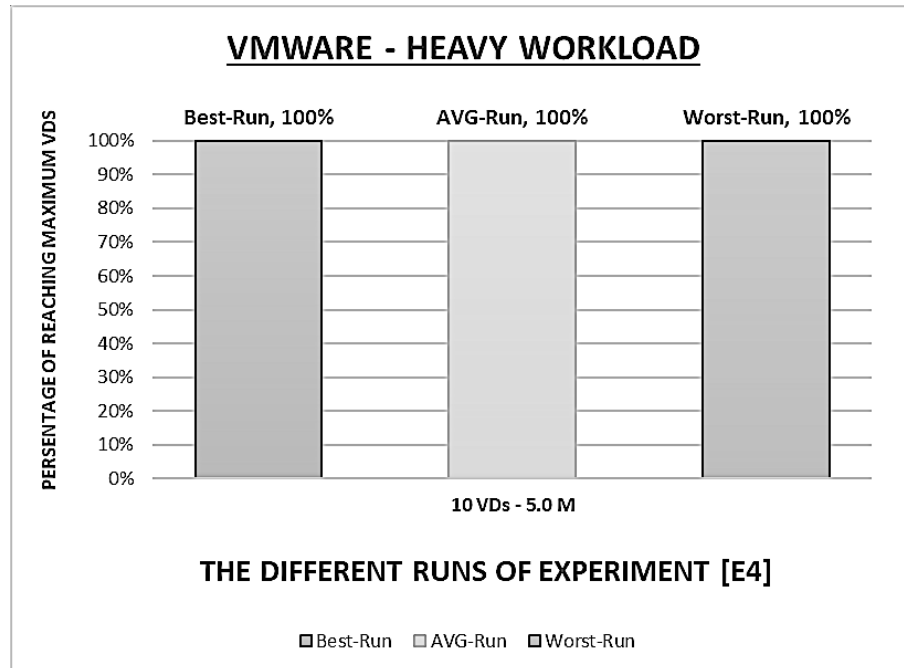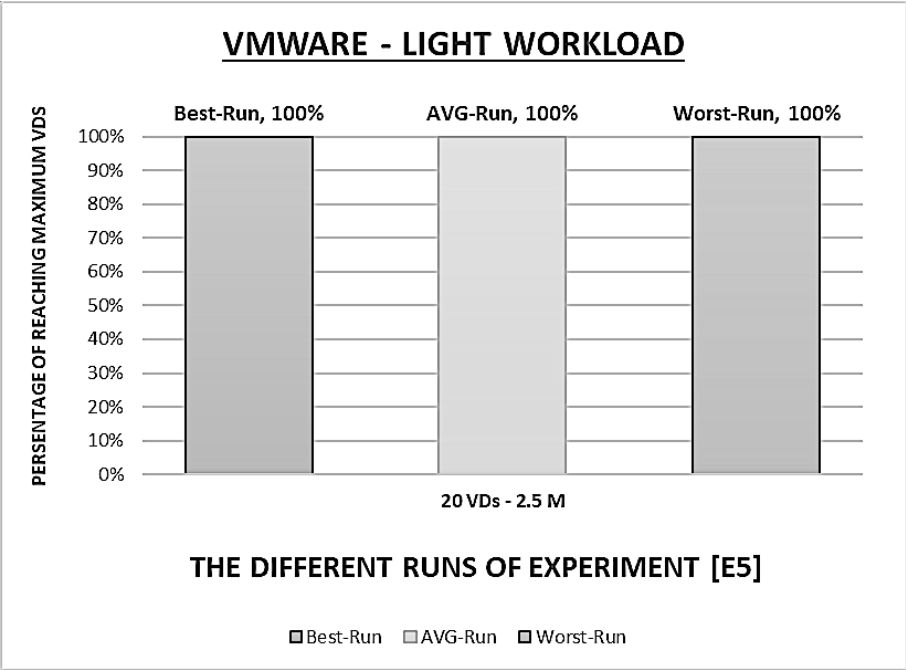
Figure 5.7: The Percentages of VMware Runs of E5.

5.4 Citrix Homogeneous Experiment
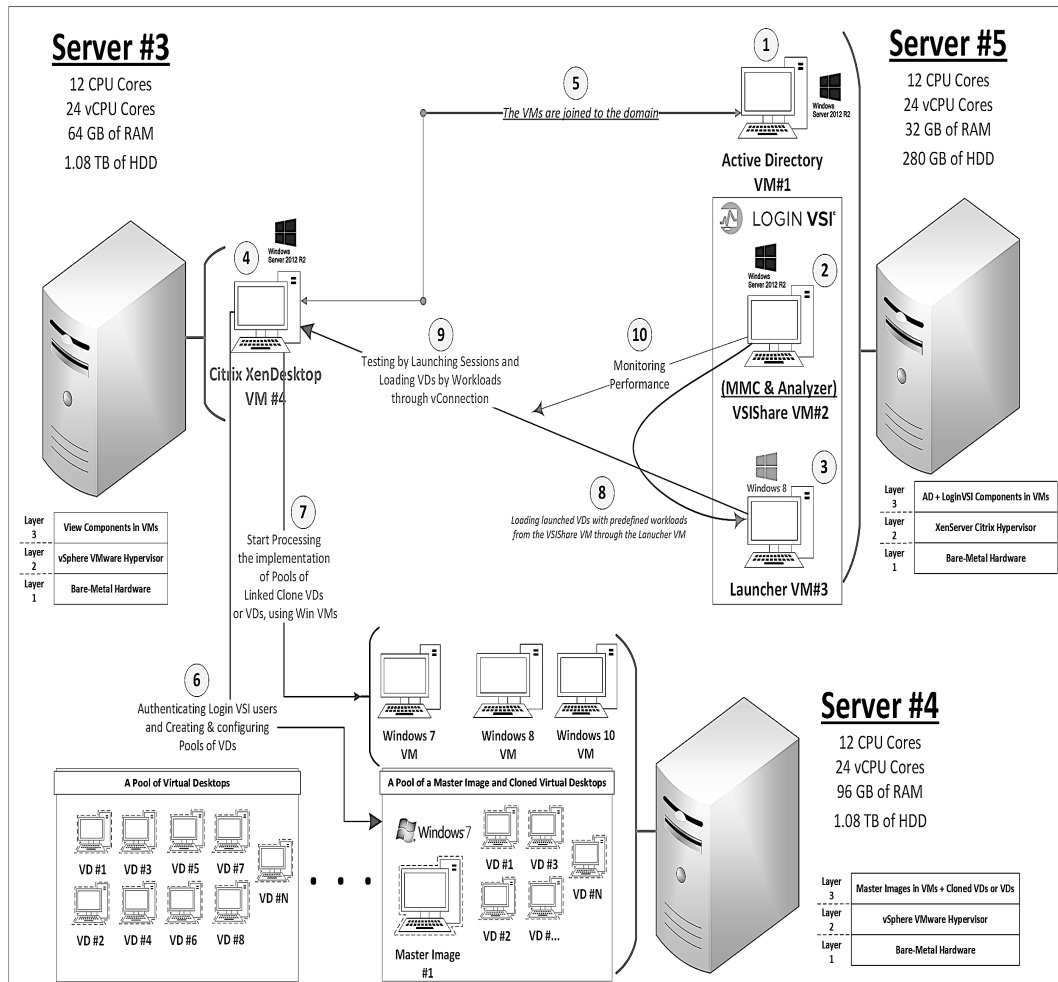
Figure 5.8: The Architecture of the Citrix Experiment

5.4.1 Citrix-Experiment Architecture and Description

The architecture of Citrix Experiment consists of three separate servers. The first server, named Server #5 as shown in Figure 5.8, should contain three virtual machines. The first virtual machine will be used as an active directory. The other two virtual machines will be used for the Login VSI benchmarking software tool (Dataserver and Launcher). They have already been explained in Chapter

2. The other two servers will be used for the Citrix VDI enviroment, named Server #3 and Server #4, as shown in Figure 5.8. Server #3 has the management component of the Citrix VDI product called (Citrix XenDesktop), while Server #4 will contain only the virtual desktops running on it and created by Citrix XenDesktop installed on Server #3 so that no other factor except the hypervisor on which VDs reside will affect the results.

The Citrix XenDesktop must be installed in a separate virtual machine on Server #3. It has a set of software components working with each other to create, configure and manage pools of VDs and then place the created VDs on Server #4. These components are Delivery Controller, Citrix Studio, Citrix Director, Citrix StoreFront, Virtual Delivery Agents and Citrix license management. All of them are installed in a single virtual machine on Server #3 making the XenDesktop easy to use since everything can be managed just from one place.

5.4.2   Citrix-Experiment HW/SW Specifications

As an infrastructure for the experimental environment, the hardware specifications used in the three servers are generally identical except the main memory size and the storage capacity as mentioned below in Table 5.10. However, Table 5.11 shows in general all the main software components installed for preparation of conducting experiments. The main reason of this table is to know exactly which versions have been used for each software component and where they are located.

Specifications	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	32 GB
Storage Capacity	HDD 1.08 TB		HDD 280 GB

Table 5.10: The Hardware Specifications of the Three Servers for Citrix Experiment

Architecture Level	Software	Version	Installed Location
Hypervisor	Citrix XenServer	7.0	Servers: #3, 4 and 5
VDI platform	Citrix XenDesktop	7.9	Server #3
Administrating Tool	XenCenter Client	7.0	Administrator Machine
Benchmarking Tool	Login VSI	4.1	Server #5
Virtual Machine	Operating System	Win S2012	Servers: #3 and 5
		Win 8	Server #5
		Win 7	Server #4

Table 5.11: The Software Specifications Installed on the Three Servers

5.4.3   Collected Results of Citrix VDI Platform

The results of the following five experiments will be presented into a few runs, only (Three Runs) extracted from the total of ten runs. These runs are categorized as Best, Average (AVG) and Worst. The best average run will be selected based on its range. For example, if the average ten runs is between 76% up to 85%, the best run which has 80% among other similar runs will be only selected and so on. Once the results of all runs have been collected, they have been directly categorized based on the maximum number of successful virtual desktops (VSImax) reached, the Baseline score and then VSImax Average (only looked at if the VSImax and Baseline are exactly equal). Specifically, the higher the capacity number reached of virtual desktops (VSImax) in the VDI environment is the better. On the other hand, the lower the Baseline score as well as VSImax Average score is the better.

For the following tables from Table [5.12] to Table [5.16], there are main parameters should be explained in detail to well understand the results contained. The test time duration is the total time of the complete test including the logging off default time (2 minutes). The inter-arrival time is the period of time where every new session can regularly access the test and it is calculated automatically by Login VSI MMC using the formula (test duration, excluding logging in default time, divided by configured VDs for test). The version of operating system and the type of workload have been specifically used. In addition, the total number of virtual desktops can be tested as maximum in the configured sessions for test.

In the results, the successful completed session is the session which has finished executing its workload successfully during the test. The unlaunched session is the session that is not able to log in and access the test. The inactive session is the session where it is launched successfully but it cannot enter the test for some hidden reason. The active session, however, can be launched and enter the test successfully. The stuck session is anything that prevents the session from executing its workload completely and successfully while it is active. However, the other parameters have been previously mentioned and explained.

- **<u>Citrix Experiment #1</u> [10-VDs, Task-Worker, 2.5-Minutes]**

As stated below in Table 5.12, the Baselines of these light-workload runs have ranged from [2047 ms as minimum and 2197 ms as maximum] by *150 ms* span. They all have the same Login VSI rating, which is *Very Poor*. Also, it must me noted that the saturation point for each run has not been reached. The reason is

that the VSImax Threshold of each run has not been reached at any time even when the maximum ten sessions were running during the whole test period of 2.5 minutes inter-arrival time.

[Citrix, 1-vCPU, 4GB-RAM]	Best-Run	AVG-Run	Worst-Run
Test Time Duration	(1440 Seconds = 24 Minutes) + 2 Minutes		
Inter-Arrival Time	Sessions logged in every 144 Seconds		
Operating System Version	Microsoft Windows 7		
Workload Type	Light (Task Worker)		
Configured Sessions for Test	(10) Virtual Desktops / Sessions		
Successful Completed Sessions	10	8	6
Unlaunched Sessions	0	0	0
Inactive Sessions	0	0	2
Stuck Sessions	0	2	2
Active Sessions	10	10	8
Performance Baseline(Rating)	2047 ms (Very Poor)	2100 ms (Very Poor)	2197 ms (Very Poor)
VSImax Index Average	1822 ms	1998 ms	2840 ms
VSImax Threshold	3047 ms	3100 ms	3197 ms
System Saturation	Not Reached	Not Reached	Not Reached

Table 5.12: The Collected Results of Citrix Experiment 1

As shown below in Figure 5.9, it is very obvious to observe that all light-workload runs have not achieved **100%** of the maximum capacity of the 10-virtual-desktops test. The results of the maximum capacity of the Best-Run, AVG-Run and Worst-Run are [**100%**, *10 VDs*], [**80%**, *8 VDs*] and [**60%**, *6 VDs*], respectively. In addition, the differences between the runs from each other are varied. For the Best-Run, it is different than the AVG-Run by **25%** while it is different than the Worst-Run by **67%**. For the AVG-Run, it is different than the Worst-Run by **33%**.

Figure 5.9: The Percentages of Citrix Runs of E1.

However, only the average run of experiment #1 is going to be discussed and taken into consideration in comparison with the similar VMware experiment in Section 5.5.3. This specific run has been selected among others to avoid bias as much as possible and exclude outliers in sampling by only choosing the average sample between the three runs.

Although the saturation point has not been reached in all the runs, there are two inactive sessions only in the worst run and also two stuck sessions in the average and worst runs in this light-workload 10-VDs test. As a result, a range of sessions starting [from at least 2 to 4 at most] were not able to complete the test successfully in the runs as total. However, a range of sessions starting [from at least 8 to 10 at most] were active during each test according to the corresponding run.

The only reasonable interpretation or justification to get such sessions as inactive, stuck or both is the clear impact of the shrinking inter-arrival time for each session in the test on the Citrix VDI platform, which is 2.5 minutes. Because every virtual desktop in the light-workload test is given 1 vCPU to execute its workload. Therefore, 10 vCPUs are needed totally. Since there are available 24 vCPUs in the server, this obviously indicates that there is no impact coming from the server hardware resources on the results at all.

- **Citrix Experiment #2** [**10-VDs, Power-Worker, 2.5-Minutes**]

As stated below in Table 5.13, the Baselines of these heavy-workload runs have ranged from [1361 ms as minimum and 1479 ms as maximum] by *118 ms* span. They all have the same Login VSI rating, which is *Fair*. Also, it must me noted that the saturation point for each run has not been reached. The reason is that the VSImax Threshold of each run has not been reached at any time even when the maximum ten sessions were running during the whole test period of 2.5 minutes inter-arrival time.

[Citrix, 2-vCPU, 4GB-RAM]	Best-Run	AVG-Run	Worst-Run
Test Time Duration	(1440 Seconds = 24 Minutes) + 2 Minutes		
Inter-Arrival Time	Sessions logged in every 144 Seconds		
Operating System Version	Microsoft Windows 7		
Workload Type	Heavy (Power Worker)		
Configured Sessions for Test	(10) Virtual Desktops / Sessions		
Successful Completed Sessions	7	5	4
Unlaunched Sessions	0	0	0
Inactive Sessions	2	0	0
Stuck Sessions	1	5	6
Active Sessions	8	10	10
Performance Baseline(Rating)	1361 ms (Fair)	1411 ms (Fair)	1479 ms (Fair)
VSImax Index Average	1723 ms	1370 ms	1279 ms
VSImax Threshold	2361 ms	2411 ms	2479 ms
System Saturation	Not Reached	Not Reached	Not Reached

Table 5.13: The Collected Results of Citrix Experiment 2

As shown below in Figure 5.9, it is very obvious to observe that all heavy-workload runs have not achieved **100%** of the maximum capacity of the 10-virtual-desktops test. The results of the maximum capacity of the Best-Run, AVG-Run and Worst-Run are [**70%**, *7 VDs*], [**50%**, *5 VDs*] and [**40%**, *4 VDs*], respectively. In addition, the differences between the runs from each other are varied except between the AVG-Run and Worst-Run. For the Best-Run, it is different than the AVG-Run by **40%** while it is different than the Worst-Run by **75%**. For the AVG-Run, it is different than the Worst-Run by **25%**.
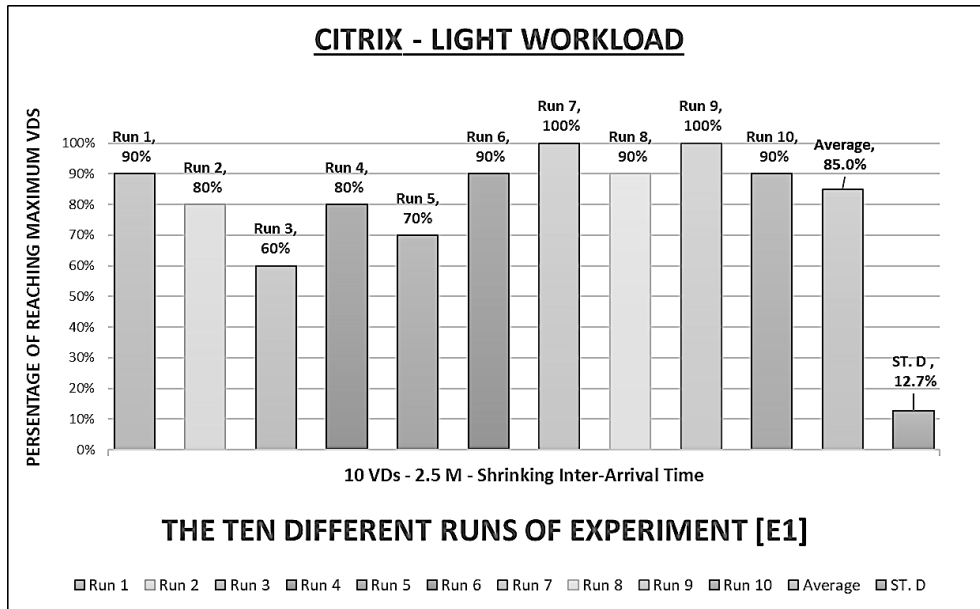
However, only the average run of experiment #2 is going to be discussed and taken into consideration in comparison with the similar VMware experiment in Section 5.5.4. This specific run has been selected among others to avoid bias as much as possible and exclude outliers in sampling by only choosing the average sample between the three runs.
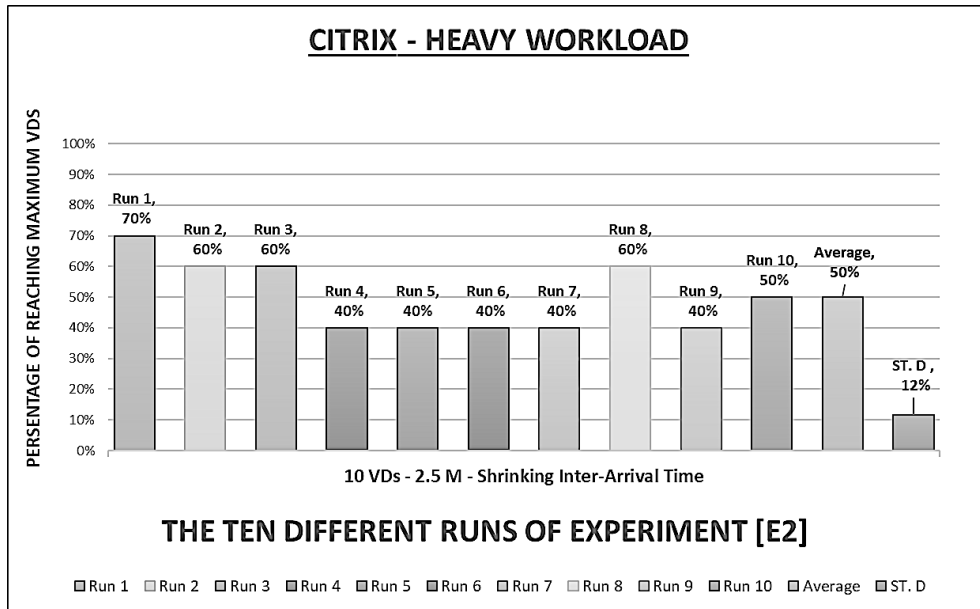
Figure 5.10: The Percentages of Citrix Runs of E2.

Although the saturation point has not been reached in all the runs, there are two inactive sessions only in the best run and a range of stuck sessions starting [from at least 1 to 6 at most] in all runs in this heavy-workload 10-VDs test. As a result, a range of sessions starting [from at least 3 to 6 at most] were not able to complete the test successfully in each run. However, a range of sessions starting [from at least 8 to 10 at most] were active during each test according to the corresponding run.

The only reasonable interpretation or justification to get such sessions as inactive, stuck or both is the clear impact of the shrinking inter-arrival time for each session in the test on the Citrix VDI platform, which is 2.5 minutes. Because every virtual desktop in the heavy-workload test is given 2 vCPU to execute its workload. Therefore, 20 vCPUs are needed totally. Since there are available 24

vCPUs in the server, this obviously indicates that there is no impact coming from the server hardware resources on the results at all.

- **Citrix Experiment #3** [**10-VDs, Task-Worker, 5.0-Minutes**]

As stated below in Table 5.14, the Baselines of these light-workload runs have ranged from [2026 ms as minimum and 2319 ms as maximum] by *293* span. They all have the same Login VSI rating, which is *Very Poor*. Also, it must me noted that the saturation point for each run has not been reached except the Worst-Run. The reason is that the VSImax Thresholds of Best-Run and AVG-Run have not been reached at any time even when the maximum ten sessions were running during the whole test period of 5.0 minutes inter-arrival time. However, the Worst-Run has indeed reached the VSImax Threshold during its test resulting in inconsistency with the two other runs.

[Citrix, 1-vCPU, 4GB-RAM]	Best-Run	AVG-Run	Worst-Run
Test Time Duration	(2880 Seconds = 48 Minutes) + 2 Minutes		
Inter-Arrival Time	Sessions logged in every 288 Seconds		
Operating System Version	Microsoft Windows 7		
Workload Type	Light (Task Worker)		
Configured Sessions for Test	(10) Virtual Desktops / Sessions		
Successful Completed Sessions	10	9	5
Unlaunched Sessions	0	0	0
Inactive Sessions	0	0	0
Stuck Sessions	0	1	0
Active Sessions	10	10	10
Performance Baseline(Rating)	2026 ms (Very Poor)	2003 ms (Very Poor)	2222 ms (Very Poor)
VSImax Index Average	2147 ms	2057 ms	1979 ms
VSImax Threshold	3026 ms	3003 ms	3222 ms
System Saturation	Not Reached	Not Reached	Reached

Table 5.14: The Collected Results of Citrix Experiment 3

As shown below in Figure 5.11, it is very obvious to observe that the light-workload Best-Run has achieved **100%** of the maximum capacity of the 10-virtual-desktops test while the AVG-Run and Worst-Run have not. The results of the maximum capacity of the Best-Run, AVG-Run and Worst-Run are [**100%**, *10 VDs*], [**90%**, *9 VDs*] and [**50%**, *5 VDs*], respectively. In addition, the differences between the runs from each other are varied except between the AVG-Run and Worst-Run. For the Best-Run, it is different than the AVG-Run by **11%** while it is different than the Worst-Run by **100%**. For the AVG-Run, it is different than the Worst-Run by **80%**.
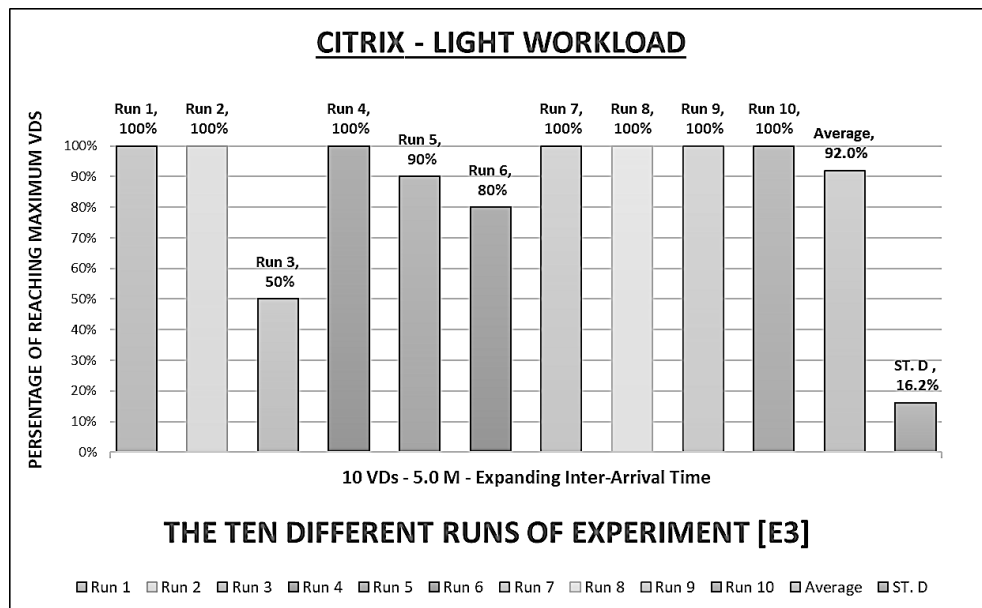

Figure 5.11: The Percentages of Citrix Runs of E3

However, only the average run of experiment #3 is going to be discussed and taken into consideration in comparison with the similar VMware experiment in Section 5.5.3. This specific run has been selected among others to avoid bias as

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much as possible and exclude outliers in sampling by only choosing the average.

- **Citrix Experiment #4** [10-VDs, Power-Worker, 5.0-Minutes]

As stated below in Table 5.15, the Baselines of these heavy-workload runs have ranged from [1321 ms as maximum and 1292 ms as minimum] by *29 ms* span. They all have the same Login VSI rating, which is *Fair*. Also, it must me noted that the saturation point for each run has not been reached. The reason is that the VSImax Threshold of each run has not been reached at any time even when the maximum ten sessions were running during the whole test period of 5.0 minutes inter-arrival time.

[Citrix, 2-vCPU, 4GB-RAM]	Best-Run	AVG-Run	Worst-Run
Test Time Duration	(2880 Seconds = 48 Minutes) + 2 Minutes		
Inter-Arrival Time	Sessions logged in every 288 Seconds		
Operating System Version	Microsoft Windows 7		
Workload Type	Heavy (Power Worker)		
Configured Sessions for Test	(10) Virtual Desktops / Sessions		
Successful Completed Sessions	10	9	7
Unlaunched Sessions	0	0	0
Inactive Sessions	0	0	0
Stuck Sessions	0	1	3
Active Sessions	10	10	10
Performance Baseline(Rating)	1321 ms (Fair)	1320 ms (Fair)	1292 ms (Fair)
VSImax Index Average	1436 ms	1444 ms	1374 ms
VSImax Threshold	2321 ms	2320 ms	2292 ms
System Saturation	Not Reached	Not Reached	Not Reached

Table 5.15: The Collected Results of Citrix Experiment 4

As shown below in Figure 5.12, it is very obvious to observe that the heavy-workload Best-Run has achieved **100%** of the maximum capacity of the 10-virtual-desktops test while the AVG-Run and Worst-Run have not. The results of the

maximum capacity of the Best-Run, AVG-Run and Worst-Run are [**100%**, *10 VDs*], [**90%**, *9 VDs*] and [**70%**, *7 VDs*], respectively. In addition, the differences between the runs from each other are varied except between the AVG-Run and Worst-Run. For the Best-Run, it is different than the AVG-Run by **11%** while it is different than the Worst-Run by **43%**. For the AVG-Run, it is different than the Worst-Run by **29%**.
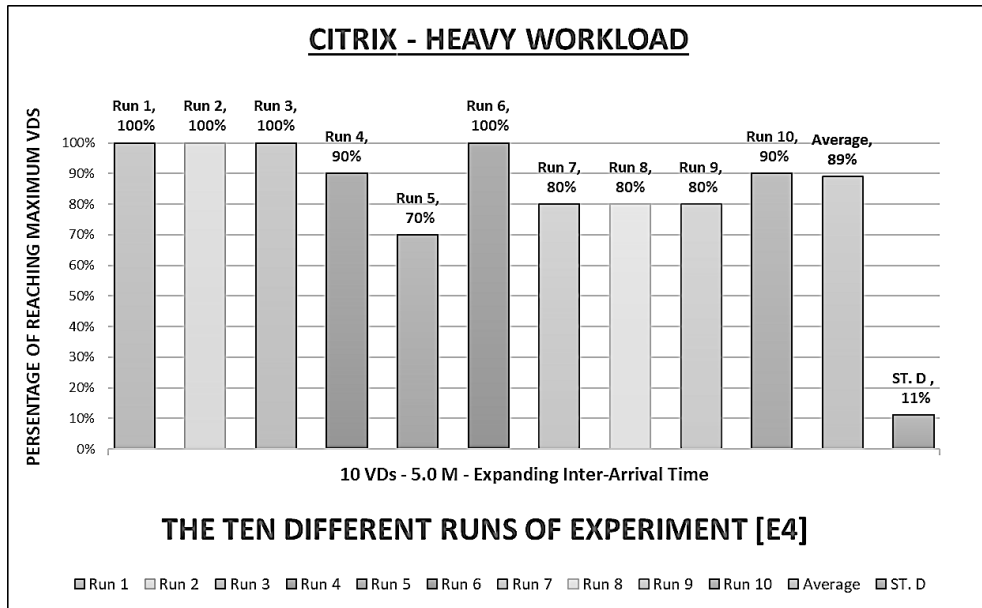

Figure 5.12: The Percentages of Citrix Runs of E4.

However, only the average run of experiment #4 is going to be discussed and taken into consideration in comparison with the similar VMware experiment in Section 5.5.4. This specific run has been selected among others to avoid bias as much as possible and exclude outliers in sampling by only choosing the average.

- **Citrix Experiment #5 [20-VDs, Task-Worker, 2.5-Minutes]**

As stated below in Table 5.16, the Baselines of these light-workload runs have ranged from [2072 ms as minimum and 2636 ms as maximum] by *564 ms* span. They all have the same Login VSI rating, which is *Very Poor*. Also, it must me noted that the saturation point for each run has been reached. The reason is that the VSImax Thresholds of all runs have indeed been reached during their tests of 2.5 minutes inter-arrival time for the twenty sessions.

[*Citrix, 1-vCPU, 4GB-RAM*]	**Best-Run**	**AVG-Run**	**Worst-Run**
Test Time Duration	(2880 Seconds = 48 Minutes) + 2 Minutes		
Inter-Arrival Time	Sessions logged in every 144 Seconds		
Operating System Version	Microsoft Windows 7		
Workload Type	Light (Task Worker)		
Configured Sessions for Test	(20) Virtual Desktops / Sessions		
Successful Completed Sessions	15	6	0
Unlaunched Sessions	0	0	0
Inactive Sessions	0	5	3
Stuck Sessions	5	3	1
Active Sessions	20	15	17
Performance Baseline(Rating)	2072 ms (Very Poor)	2636 ms (Very Poor)	2570 ms (Very Poor)
VSImax Index Average	2087 ms	2356 ms	3757 ms
VSImax Threshold	3072 ms	3636 ms	3570 ms
System Saturation	NOT Reached	Reached	Reached

Table 5.16: The Collected Results of Citrix Experiment 5

As shown below in Figure 5.13, it is very obvious to observe that all light-workload runs have not achieved **100%** of the maximum capacity of the 20-virtual-desktops test. The results of the maximum capacity of the Best-Run, AVG-Run and Worst-Run are [**75%**, *15 VDs*], [**30%**, *6 VDs*] and [**0%**, *0 VDs*], respectively. In addition, the differences between the runs from each other are varied. For the Best-Run, it is different than the AVG-Run by **150%** while it is different than

the Worst-Run by **1500%**. For the AVG-Run, it is different than the Worst-Run by **600%**.

However, only the average run of experiment #5 is going to be discussed and taken into consideration in comparison with the similar VMware experiment in Section 5.5.3. This specific run has been selected among others to avoid bias as much as possible and exclude outliers in sampling by only choosing the average.
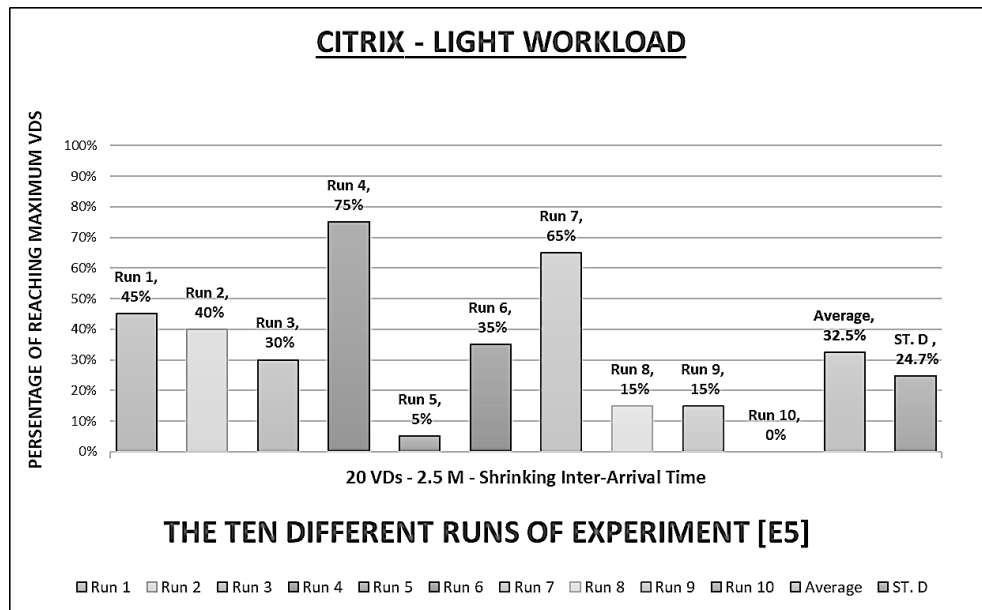
Figure 5.13: The Percentages of Citrix Runs of E5.

The saturation point has been reached in every run. In addition, there are a range of inactive sessions starting [from at least 3 to 5 at most] and a range of stuck sessions starting [from at least 1 to 5 at most] in all runs in this light-workload 20-VDs test. As a result, eight sessions were not able to complete the test successfully in each run. However, a range of sessions starting [from at least 15 to 20 at most] were active during each test according to their corresponding

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runs.

The only reasonable interpretation or justification to get such sessions as inactive, stuck or both is the clear impact of the shrinking inter-arrival time for each session in the test on the Citrix VDI platform, which is 2.5 minutes. Because every virtual desktop in the light-workload test is given 1 vCPU to execute its workload. Therefore, 20 vCPUs are needed totally. Since there are available 24 vCPUs in the server, this obviously indicates that there is no impact coming from the server hardware resources on the results at all.

5.5   Comparisons Between VMware and Citrix

Most importantly, the reader should take the following comparisons with caution. For technical reasons, the VMware VDI experiments conducted could not be more than three runs. On the other hand, the Citix VDI experiments conducted were ten runs each. Therefore, the results from this section should be carefully validated. For proper comparisons, the VMware VDI experiments should be ten runs each to become a fair assessment between the two VDI platforms.

5.5.1   Baseline Comparison

As importantly mentioned before, whenever the baseline becomes lower, the VDI environment will be better. Table 5.17 and Figure 5.14 illustrate clearly the accurate differences between the baselines of VMware and Citrix experiments.

Experiment #	VMware Baseline	Login VSI Rating	Citrix Baseline	Login VSI Rating	Difference
E1	1261 ms	Fair	2100 ms	Very Poor	-67 %
E2	949 ms	Good	1411 ms	Fair	-49 %
E3	1232 ms	Fair	2003 ms	Very Poor	-63 %
E4	982 ms	Good	1320 ms	Fair	-34 %
E5	1299 ms	Fair	2637 ms	Very Poor	-103 %

Table 5.17: The Summary of Baseline Comparisons Between Experiments.
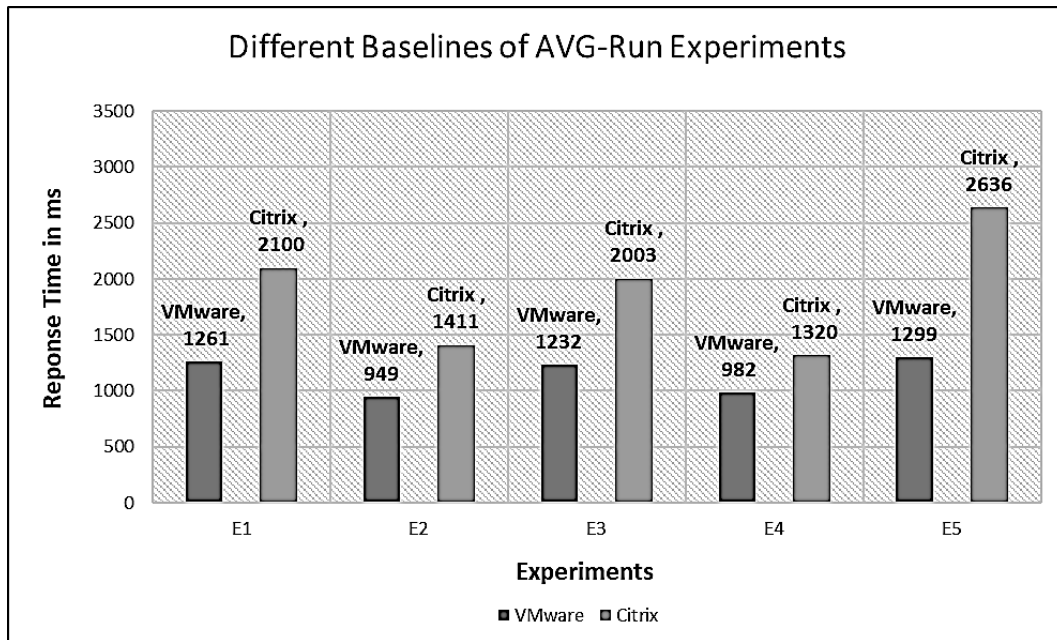
Figure 5.14: The VMware and Citrix Baselines in AVG-Run Experiments.

- **Experiment #1** **[10-VDs, 2.5-Minutes, Light-Workload]**

Based on what stated in Table 5.17, the baselines of the AVG-Run experiment #1
for VMware and Citrix VDI platforms are [1261 ms] and [2100 ms], respectively.
Also, the rating of VMware baseline is [*Fair*] while the rating of Citrix baseline is
[*Very Poor*]. Remarkably, the VMware baseline is lower than the Citrix baseline
by **67 %**. This clearly indicates that the VMware VDI Platform is much suitable

than the Citrix VDI platform in terms of the baseline in the experiment #1 conducted.

- **<u>Experiment #2</u> [10-VDs, 2.5-Minutes, Heavy-Workload]**

Based on what stated in Table 5.17, the baselines of the AVG-Run experiment #2 for VMware and Citrix VDI platforms are [949 ms] and [1411 ms], respectively. Also, the rating of VMware baseline is [*Good*] while the rating of Citrix baseline is [*Fair*]. Remarkably, the VMware baseline is lower than the Citrix baseline by **49 %**. This clearly indicates that the VMware VDI Platform is much suitable than the Citrix VDI platform in terms of the baseline in the experiment #2 conducted.

- **<u>Experiment #3</u> [10-VDs, 5.0-Minutes, Light-Workload]**

Based on what stated in Table 5.17, the baselines of the AVG-Run experiment #3 for VMware and Citrix VDI platforms are [1232 ms] and [2003 ms], respectively. Also, the rating of VMware baseline is [*Fair*] while the rating of Citrix baseline is [*Very Poor*]. Remarkably, the VMware baseline is lower than the Citrix baseline by **63 %**. This clearly indicates that the VMware VDI Platform is much suitable than the Citrix VDI platform in terms of the baseline in the experiment #3 conducted.

- **<u>Experiment #4</u> [10-VDs, 5.0-Minutes, Heavy-Workload]**

Based on what stated in Table 5.17, the baselines of the AVG-Run experiment #4 for VMware and Citrix VDI platforms are [982 ms] and [1320 ms], respectively.

Also, the rating of VMware baseline is [*Good*] while the rating of Citrix baseline is [*Fair*]. Remarkably, the VMware baseline is lower than the Citrix baseline by **34 %**. This clearly indicates that the VMware VDI Platform is much suitable than the Citrix VDI platform in terms of the baseline in the experiment #4 conducted.

- **Experiment #5 [20-VDs, 2.5-Minutes, Light-Workload]**

Based on what stated in Table 5.17, the baselines of the AVG-Run experiment #5 for VMware and Citrix VDI platforms are [1299 ms] and [2636 ms], respectively. Also, the rating of VMware baseline is [*Fair*] while the rating of Citrix baseline is [*Very Poor*]. Remarkably, the VMware baseline is lower than the Citrix baseline by **103 %**. This clearly indicates that the VMware VDI Platform is better than the Citrix VDI platform in terms of the baseline in the experiment #5 conducted.

5.5.2   The Final Result of Baseline Comparisons

Table 5.17 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 is obviously much suitable than Citrix VDI platform in all the five experiments, which are E1, E2, E3, E4 and E5 due to the lower baselines.

5.5.3 Light-Workload VSImax Comparison

- **Experiment #1** [10-VDs, 2.5-Minutes]

As shown in Figure 5.15 below, the significant observation of the E1 comparison is the following. The VMware VDI platform has reached the maximum capacity which is 10 out of 10 VDs while the Citrix VDI platform has reached only 8 out 10 VDs. As a result, the VMware VDI platform is much suitable than the Citrix VDI platform by **25 %** difference in this specific test.

Figure 5.15: The Comparison Between the Light Workload AVG-Runs of E1.

Also, as stated in Table 5.18 below, the VMware VDI platform does not have any inactive or stuck sessions whereas the Citrix VDI platform does. The number of active sessions of Citrix VDI platform are 10 out of 10 VDs. Two of those active ten sessions were in a stuck state. However, the saturation point of both VDI platforms have not been reached.

Experiment #1	VMware VDI Platform	Citrix VDI Platform
VSImax	[10]	[8]
Unlaunched Sessions	0	0
Inactive Sessions	0	0
Stuck Sessions	0	2
Active Sessions	10	10
System Saturation	NOT REACHED	NOT REACHED

Table 5.18: Average Run Comparison Between the Pair of VDI Platforms for E1

- **Experiment #3** [**10-VDs, 5.0-Minutes**]

As shown in Figure 5.16 below, the significant observation of the E3 comparison is the following. The VMware and Citrix VDI platforms have reached the same maximum capacity which is 10 out of 10 VDs while the Citrix VDI platform has reached only 9 out 10 VDs. As a result, the VMware VDI platform is much suitable than the Citrix VDI platform by **11 %** difference in this specific test.
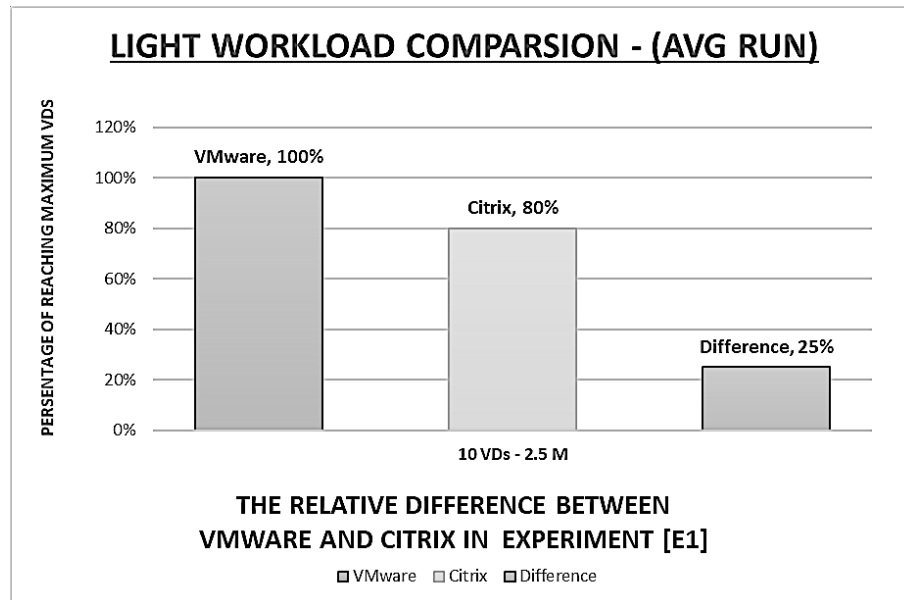

Figure 5.16: The Comparison Between the Light Workload AVG-Runs of E3.

Also, as stated in Table 5.19 below, the VMware and Citrix VDI platforms

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do not have any inactive or stuck sessions whereas the Citrix VDI platform does. The number of active sessions of Citrix VDI platform are 10 out of 10 VDs. One of those active ten sessions was in a stuck state. However, the saturation point of both VDI platforms have not been reached.

Experiment #3	VMware VDI Platform	Citrix VDI Platform
VSImax	[10]	[9]
Unlaunched Sessions	0	0
Inactive Sessions	0	0
Stuck Sessions	0	1
Active Sessions	10	10
System Saturation	NOT REACHED	NOT REACHED

Table 5.19: Average Run Comparison Between the Pair of VDI Platforms for E3

- **Experiment #5** [20-VDs, 2.5-Minutes]

As shown in Figure 5.17 below, the significant observation of the E5 comparison is the following. The VMware VDI platform has reached the maximum capacity which is 20 out of 20 VDs while the Citrix VDI platform has reached only 6 out 20 VDs. As a result, the VMware VDI platform is better than the Citrix VDI platform by **233 %** difference in this specific test.
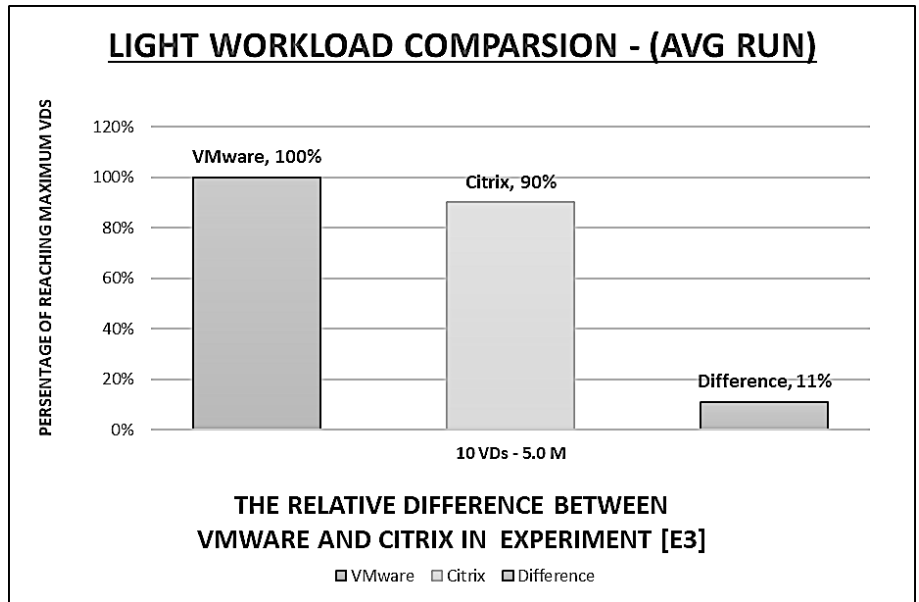
Figure 5.17: The Comparison Between the Light Workload AVG-Runs of E5.

Also, as stated in Table 5.20 below, the VMware VDI platform does not have any inactive or stuck sessions whereas the Citrix VDI platform does. The number of active sessions of Citrix VDI platform are 15 out of 20 VDs. three of those active fifteen sessions was in a stuck state and the other missing five sessions were inactive and did not logged into the whole test at any time although they were launched successfully. However, the saturation point of VMware VDI platforms has not been reached while the Citrix VDI platform has indeed been saturated by reaching the Threshold VSImax during the test.

Experiment #5	**VMware VDI Platform**	**Citrix VDI Platform**
VSImax	[20]	[6]
Unlaunched Sessions	0	0
Inactive Sessions	0	5
Stuck Sessions	0	3
Active Sessions	20	15
System Saturation	NOT REACHED	*REACHED*

Table 5.20: Average Run Comparison Between the Pair of VDI Platforms for E5

5.5.4   Heavy-Workload VSImax Comparison

- **Experiment #2** [10-VDs, 2.5-Minutes]

As shown in Figure 5.18 below, the significant observation of the E2 comparison is the following. The VMware VDI platform has reached the maximum capacity which is 10 out of 10 VDs while the Citrix VDI platform has reached only 5 out 10 VDs. As a result, the VMware VDI platform is much suitable than the Citrix VDI platform by **100 %** difference in this specific test.
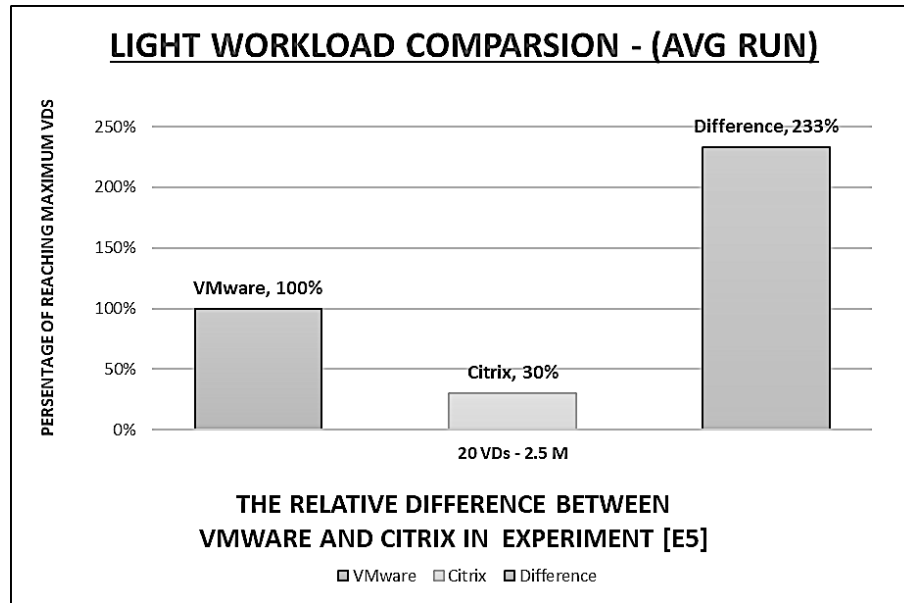

Figure 5.18: The Comparison Between the Heavy Workload AVG-Runs of E2.

Also, as stated in Table 5.21 below, the VMware VDI platform does not have any inactive or stuck sessions whereas the Citrix VDI platform does. The number of active sessions of Citrix VDI platform are 10 out of 10 VDs. Five of those active ten sessions were in a stuck state. However, the saturation point of both VDI platforms have not been reached.

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Experiment #2	VMware VDI Platform	Citrix VDI Platform
VSImax	[10]	[5]
Unlaunched Sessions	0	0
Inactive Sessions	0	0
Stuck Sessions	0	5
Active Sessions	10	10
System Saturation	NOT REACHED	NOT REACHED

Table 5.21: Average Run Comparison Between the Pair of VDI Platforms for E2

- **Experiment #4** [**10-VDs, 5.0-Minutes**]

As shown in Figure 5.19 below, the significant observation of the E4 comparison is the following. The VMware and Citrix VDI platforms have reached the same maximum capacity which is 10 out of 10 VDs while the Citrix VDI platform has reached only 9 out 10 VDs. As a result, the VMware VDI platform is much suitable than the Citrix VDI platform by **11 %** difference in this specific test.
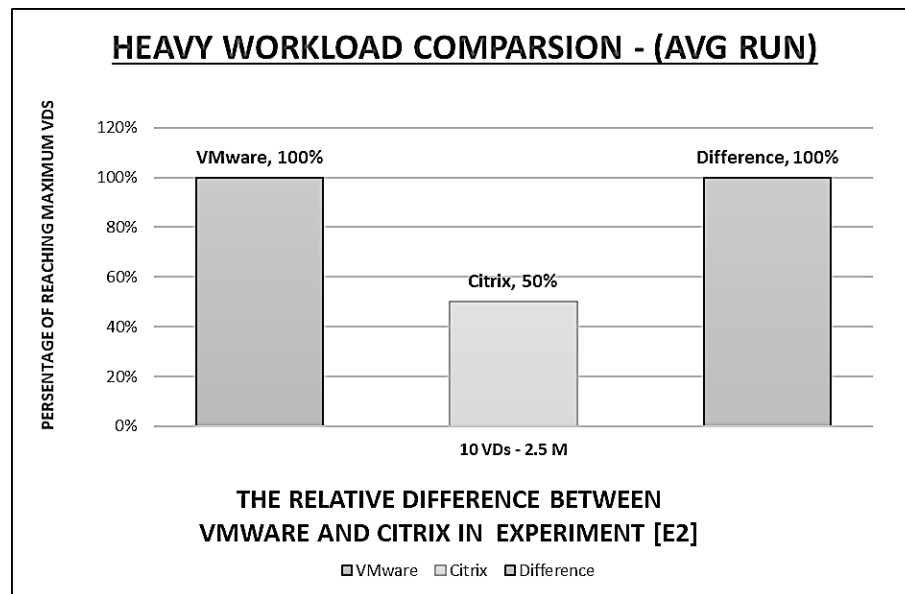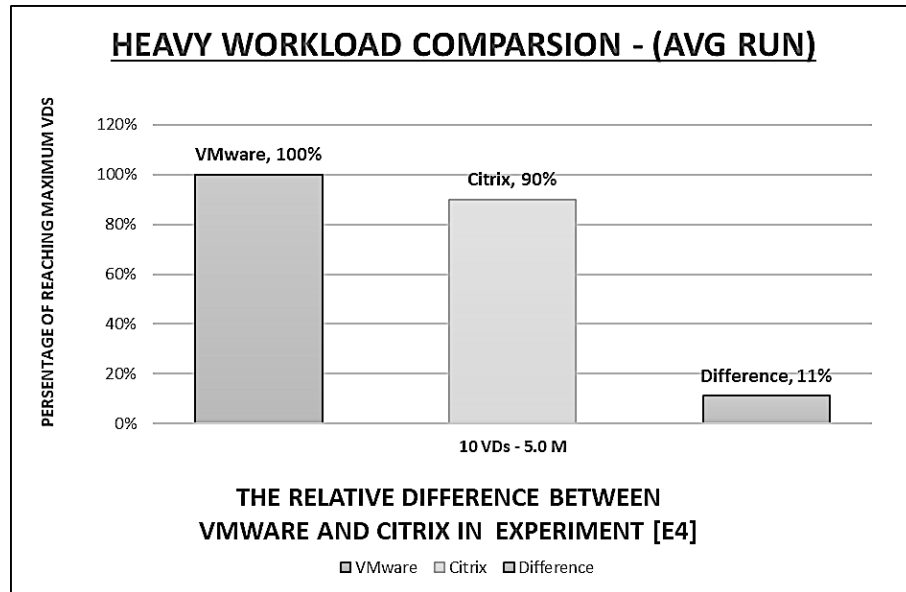

Figure 5.19: The Comparison Between the Heavy Workload AVG-Runs of E4.

Also, as stated in Table 5.22 below, the VMware and Citrix VDI platforms

do not have any inactive or stuck sessions whereas the Citrix VDI platform does. The number of active sessions of Citrix VDI platform are 10 out of 10 VDs. One of those active ten sessions was in a stuck state. However, the saturation point of both VDI platforms have not been reached.

Experiment #4	VMware VDI Platform	Citrix VDI Platform
VSImax	[10]	[9]
Unlaunched Sessions	0	0
Inactive Sessions	0	0
Stuck Sessions	0	1
Active Sessions	10	10
System Saturation	NOT REACHED	NOT REACHED

Table 5.22: Average Run Comparison Between the Pair of VDI Platforms for E4

5.5.5 The Final Result of VSImax Comparisons

Table 5.23 shows the summary of VSImax comparisons for all experiments. The aim is to extract the final result from these comparisons as another part of an answer to the thesis problem statement. Therefore, the result based on the maximum capacity (VSImax) is that VMware VDI platform is much suitable than Citrix VDI platform in all the experiments, .

	VMware	Citrix	The Suitability Result	Percentage
Experiment #1	10	8	VMware	25 %
Experiment #2	10	5	VMware	100 %
Experiment #3	10	9	VMware	11 %
Experiment #4	10	9	VMware	11 %
Experiment #5	20	6	VMware	233 %

Table 5.23: The Summary of VSImax Comparisons Between Experiments.

5.6 Comparisons with Paper [15]

The aim of conducting homogeneous and heterogeneous experiments with respect to Login VSI in the paper as mentioned is to test the suitability of the VDI systems in high-stress environments. However, the authors did not mention the versions of the used VDI platforms as opposed to what is clearly specified in this thesis. Also, the workloads which have been used in the paper's experiments are most probably customized rather than standard and predefined by Login VSI while the work in the thesis have used two of the Login VSI predefined workloads.

As for the results of the paper, it shows that only one run has been conducted for each one of their experiments. Although the authors have tested their VDI platforms by a high number of virtual desktops as opposed to twenty virtual desktops as maximum in the thesis, their results of the homogeneous experiments show the following. In terms of the baseline, the results of the paper and the results of the thesis are similar since the VMware VDI platform always show lower baselines than Citrix VDI baselines. However, in terms of the VSImax, based on the light customized workload used in the paper, it shows that the Citrix VDI is much suitable than the VMware VDI in a high number of virtual desktops while they are similar in the heavy customized workload used in the paper. Since the workload type and the number of virtual desktops play major roles, there will be a need for further research in order to make the results validated and find a reasonable interpretation for the current both results.

5.7 Insights and Lessons Learned of the Results

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.

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.

5.8 Threats to Validity

The results obtained suffer from limitations, which means that they cannot be generalized due to two factors. Firstly, the specifications of the hardware used in the experiments can be easily changed. For example, the type of storage device may be replaced from being HDD to SSD. This may lead to collecting different results and probably drawing different conclusions.

Also, the versions of the VDI platforms produced by various venders that have been examined and compared might play a minor role in obtaining varied results as the venders always try hard to enhance their VDI platform products in the versions of future releases. Therefore, the results obtained are limited to the specific VDI platform versions used for VMware and Citrix and cannot be generalized as well. Moreover, the results obtained from the experiments conducted have confidence levels that might not be enough by which the good decision is going to be made since it will be relied on only three runs for each experiment. In order to increase the confidence levels on the results, there will be a need for adding extra multiple runs of the same experiments.

Also, the version of the operating system used in the experiments conducted is only Windows 7. The specific purpose of choosing this version is to just narrow the scope of this thesis. Thus, other Windows versions like Windows 8 and 10 have not been included which might lead to different conclusions. Therefore, the results collected will be only limited to the Windows version used and cannot be generalized.

CHAPTER 6

CONCLUSION AND FUTURE

WORK

6.1   Conclusion

The conclusions can be taken as an initial step towards utilizing cloud environments in teaching and research activities by using the VDI platform technology either from VMware or Citrix venders to enhance educational environments. Therefore, 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 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 five experiments is that the VMware VDI platform has a very high level of consistency.

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 E5. 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 experiments, E1, E2 and E5, is that the Citrix VDI platform has a very low level of consistency.

According to the experiments E1, E2 and E5, 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. However, the results of the runs of only E3 and E4 have reached the maximum capacities of their tests in some of their runs.

The comparisons of the five experiments between VMware and Citrix VDI platforms in terms of VSImax and Baseline shows bases on the results collected that the VMware VDI platform is much suitable for educational environments than the Citrix VDI platform within their homogeneous environment. Although the work in the thesis has been completed showing that the VMware VDI is much suitable than the Citrix VDI, there is an important complementary work consisting of two parts which should be accomplished by other researchers.

The first part is get a fair assessment between the two platforms by performing a comparison between ten runs of each VDI platform. The last part, 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. However, the same experiments of the VMware VDI platform cannot be conducted on the Citrix XenServer hypervisor as a heterogeneous environment since it is unfeasible at the present time but it would be expected to be feasible in the near future.

6.2   Future Work

In this research, LoginVSI has been used for monitoring VDs' environments as a standard benchmarking software tool. However, there are a number of other benchmarking software tools, either commercial or open-source. They can be used in order to validate the work accomplished here for the same experiments.

As another future investigation, the maximum number of VDs running are specified by [10 or 20 VDs] in a test in this work for each experiment. Therefore, there is a possibility to increase the maximum number of VDs in a test by a greater number in the same experiments instead of the current numbers. The results that would be obtained can either support the current conclusions and make them much stronger or easily refute them.

As an alternative work, the maximum number of VDs stays as [10 or 20 VDs] but with using SSD storage device instead of what has been used in this thesis, which is HDD. It could be also leaving the hardware specifications as it is but instead of using Windows 7 in virtual desktops, other Windows versions should be included and used so that the conclusions of this work can be strongly supported.

Also, 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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