Multipurpose Cloud-based Distance Learning Laboratory: A Case Study

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***Abstract*—Several ways exist to offer online and distance learning through Internet, i.e., starting from exposing the bare metal machines to building scalable and elastic cloud solution, which can offer its resources in different ways, on demand. The cloud abstracts the hardware, making it a perfect solution for offering university facilities on Internet (online). In this paper we explore the challenges and several approaches for traditional laboratories. We also present a case study of practical transformation of traditional computer laboratory to a state-of-the-art online cloud laboratory.**

***Index Terms*—*Cloud Computing*; *Education*; *Online learning*.**

I. Introduction

Universities all around the world "must" use Internet as an infrastructure for distance learning. Without distance learning, a university will be isolated in today's dynamic world. Also, one of the main problems is that universities have limited budget for laboratories. The appropriate solution should offer a low-cost and architecture that will fulfill the pre-known purposes and the future expanding purposes [4].

The increased number of enrolled students in a course, even up to 100.000 students for some courses, enforced universities to move the classical blended learning to distance learning. Remote and virtual laboratories can improve students' learning outcomes [9]. However, they offer predefined and limited experiments and exercises [7]. Caminero et al. [2] proposed a new concept of Laboratory as a Service (LaaS), which allows the students a remote laboratory adapted to their needs.

With the introduction of the open-source cloud computing platforms, universities have a chance to set up a massive cloud platforms on the existing hardware with zero cost. Also, the openness of these cloud computing platforms make them an ideal solution for universities all around the world, because the software of the cloud platform could be customized as universities like. These open source cloud computing platforms offer custom deployment model and are independent of other proprietary (commercial) software.

In this paper we present a case study on how to transfer the traditional laboratory to the cloud based one in order to allow distance learning for multiple courses. Based on the challenges of the traditional laboratory, we use the best practice of all approaches and use them into the cloud.

The rest of the paper is organized as follows. The challenges of a traditional laboratory are presented in Section II. The possible solutions and improvements are presented in Section III. The case study of the scalable and elastic cloud-based laboratory is presented in Section IV. Finally, Section V concludes our work and presents a plan for future work.

II. Traditional Laboratories's Challenges

Usually, a traditional laboratory is mostly used for conducting lab exercises for a single or a small group of courses. This section briefly describes the challenges that arise from a traditional laboratory.

A. Hardware Challenges

A huge challenge for universities is to choose the appropriate laboratory equipment that will fulfill different requirements of all courses. Different knowledge areas (KAs) require equipment with specific characteristics. ACM/IEEE present 18 KAs in their CS (Computer Science) report [1]. We use this classification in order to determine the hardware requirements for a particular KA, classified as Low (L), Medium (M) or High (H). Low resource requirements means one core, less than 1GB main memory or 100Mbps for CPU, RAM and IO, correspondingly. Medium means 2-4 CPU cores, 2-4GB or 1Gbps, and High is used for 6-8 CPU cores, 6-8GB and up to 10Gbps.

Figure 1 depicts the summary report of the hardware requirements for each KA that laboratory should cover. For example, Parallel and Distributed Computing KA requires hardware with more than 4 CPU cores and a lot of RAM, while the Networking and Communication KA don't depend on the CPU cores and the size of the RAM. That is, some KA need multi-core CPUs, another a lot of RAM memory, while others need high-bandwidth Internet connection.

B. Software Challenges

Each KA requires not only a certain amount of hardware resources, but a specific application software and different operating systems, as well. Similar to hardware requirements, Figure 2 depicts the summary report of the software requirements for each KA that laboratory should cover. For example, a laboratory can be installed with Linux or Windows operating system for Architecture and Organization KA, but usually Linux operating system is used for Operating Systems KA. To conclude, some KAs require only Linux operating system, others with Windows, and some KAs do not depend on the operating system.

Knowledge Area	Hardware Requirements								
	CPU Cores			*RAM*			*I/O*		
	L	M	H	L	M	H	L	M	H
Algorithms and Complexity	×	×	✓	×	✓	×	×	✓	×
Architecture and Organization	×	✓	×	✓	×	×	×	✓	×
Computational Science	×	×	✓	×	×	✓	×	×	✓
Discrete Structures	✓	×	×	✓	×	×	✓	×	×
Graphics and Visualization	×	✓	×	×	×	✓	×	×	✓
Human-Computer Interaction	✓	×	×	✓	×	×	✓	×	×
Information Assurance and Security	×	✓	×	×	✓	×	×	✓	×
Information Management	✓	×	×	✓	×	×	✓	×	×
Intelligent Systems	×	✓	×	×	✓	×	×	✓	×
Networking and Communications	✓	×	×	✓	×	×	✓	×	×
Operating Systems	✓	×	×	✓	×	×	✓	×	×
Platform-based Development	✓	×	×	✓	×	×	✓	×	×
Parallel and Distributed Computing	×	×	✓	×	×	✓	×	×	✓
Programming Languages	×	✓	×	×	✓	×	×	✓	×
Software Development Fundamentals	✓	×	×	✓	×	×	✓	×	×
Software Engineering	×	✓	×	×	✓	×	×	✓	×
Systems Fundamentals	×	✓	×	×	✓	×	×	✓	×
Social Issues and Professional Practice	✓	×	×	✓	×	×	✓	×	×

Fig. 1. Summary report of the hardware requirements for each KA

Knowledge Area	Software Requirements	
	System Software	
	W	L
Algorithms and Complexity	✓	×
Architecture and Organization	✓	✓
Computational Science	✓	×
Discrete Structures	✓	×
Graphics and Visualization	✓	✓
Human-Computer Interaction	✓	✓
Information Assurance and Security	✓	✓
Information Management	✓	×
Intelligent Systems	✓	×
Networking and Communications	✓	×
Operating Systems	×	✓
Platform-based Development	✓	×
Parallel and Distributed Computing	✓	✓
Programming Languages	✓	✓
Software Development Fundamentals	✓	×
Software Engineering	✓	✓
Systems Fundamentals	✓	✓
Social Issues and Professional Practice	✓	×

Fig. 2. Summary report of the software requirements for each KA

Another challenge is the type of the applications. The 16-bit applications are not supported on modern operating systems and many 32-bit application do not work properly on 64-bit operating systems since they run in an emulator [5].

C. *Life-Cycle Problem*

Another challenge is the hardware's life-cycle, which is usually three to five years. IT Managers must choose appropriate equipment that will offer optimal performance and fulfill all requirements within the limited laboratory budget. However, practice shows that most of the time the laboratory equipment will be either over-utilized (during assessments, activity deadlines or course enrollments) or under-utilized (during weekends and holidays).

III. Further Steps Towards Improvements

This section presents the possible solutions for the challenges that raise for a traditional laboratory.

A. *Isolated Workstation per KA*

Maybe the most naive solution is to isolate a separate workstation, or even a separate laboratory per KA. This is maybe the best solution, because the applications of each KA are isolated among each other. Still, this is not a good solution. For example, the Networking and Communications KA requires two different operating systems.

B. *Group Several KAs per Operating System*

A step further is to group several KAs onto one workstation. This will mitigate the previous challenge, but unfortunately it raises another. That is, the programs are not isolated among each other, and usually they impact on each other. Also, some programs are 16-bit, 32-bit or 64-bit.

Also, these resources are unbalanced. This means that workstations will be under-utilized for some KAs that require a low amount of resources, while sometimes they will be over-utilized for KAs that need huge amount of RAM or CPUs.

A better solution is to create an image of virtual machine (VM) and to deploy on each workstation. This solution is used in our faculty, but there are 124 installed applications in the Windows type image. Still, there are two different VMs, each for Linux- and Windows-based programs.

C. *VM per KA*

The next step is to isolate a VM per KA. This solution is maybe a solution for the previously mentioned challenges, but still it raises an additional one. That is, the administration becomes distributed now, instead of being centralized. Also, each VM will keep huge hard drive space on each workstation, which is limited due to huge number of KAs.

D. *Cloud-based Online Laboratory*

Considering all presented challenges, a cloud-based online laboratory is an appropriate solution, which implements all advantages of each approach. Cloud environment has a theoretically infinite amount of resources, and it is easy to implement a separate VM per KA. The cloud scalability can instantiate a VM instance with arbitrary number of CPU cores and RAM memory. Even more, additional volumes can be attached for computer graphic courses. Therefore, we started to develop a traditional laboratory in cloud based one. The next section presents a case study.

IV. Case Study for Cloud Based Laboratory

This section briefly describes the case study of the architecture of the cloud-based laboratory.

A. *Equipment*

The equipment of the laboratory consists of 18 workstations, 1 high-end Mac Pro server, 1 Cisco switch, and 1 Cisco router. Our goal is to find an optimal solution (appropriate architecture) from the existing equipment in the laboratory, which will primarily fulfill the research purpose, as well the need of the other requirements like faculty courses, faculty projects and other activities.

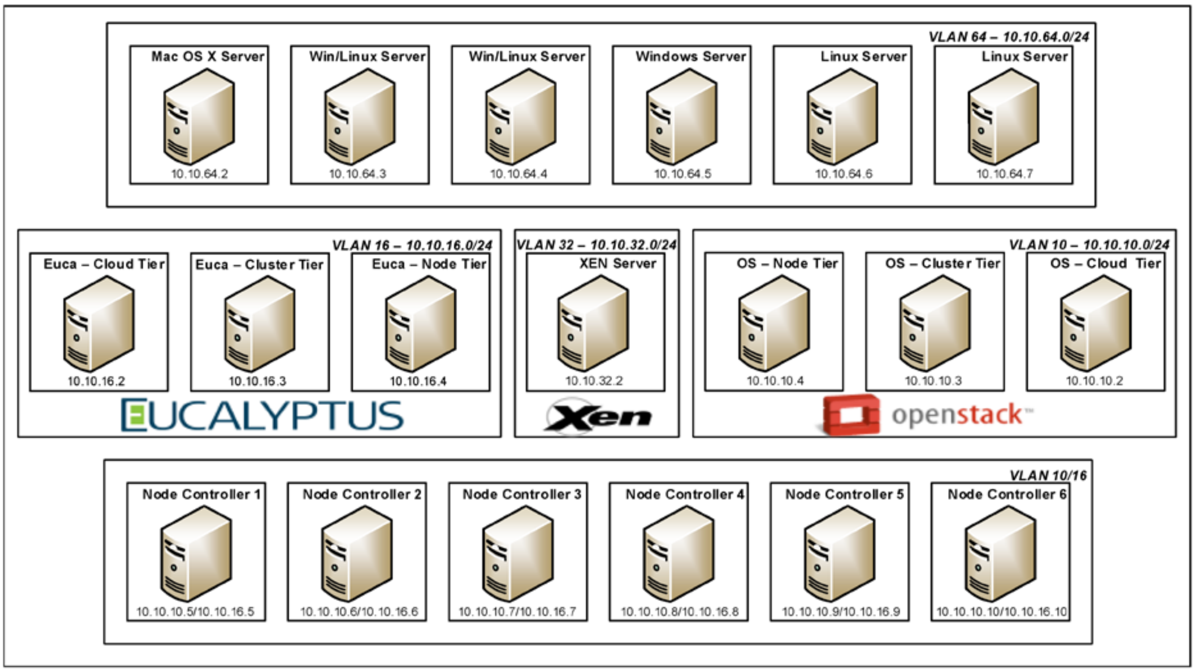

Fig. 3. Case study of the cloud based laboratory

B. Finding an Optimal Solution

Figure 3 depicts the optimal architecture of the laboratory.

Our experience with open source clouds has shown that we need to install and configure two different open source clouds due to compatibility issues. More details about how we have implemented two clouds are presented in [8].

A lot of open source cloud software frameworks exist on the market, but we look for the best ranked, well-known and enterprise-like open source clouds. After in-depth research and benchmarking, we conclude that we need to deploy the Eucalyptus [3] and OpenStack [6] cloud frameworks.

Using two clouds provides a redundancy. That is, if a single cloud fails, the compute nodes can be migrated immediately in the other cloud, and VMs can be instantiated with acceptable delay.

For optimal installation and performances of both cloud platforms, we needed three workstations by cloud platform, which will be enough to form a complete Infrastructure as a Service (IaaS) cloud, and 6 more workstations called ”node controllers group”, which will scale the performances. Both cloud platforms could instantiate max of four VMs with two cores and two GB of RAM, without the need of the six additional workstations.

Since this is the pilot project, this laboratory is intended for the courses that are taught by the authors. That is, Computer Architecture and Organization, Microprocessors and Micro-controllers, Teamwork, Internet, High Performance Computing (HPC) and Computer Networks. We can fulfill these needs for the listed courses with four workstations, by two Windows and Linux operating systems. These so-called ”student” workstations, are configured with remote access and the admin / root access will be given to all students that participate in the listed courses, as they could remotely exercise on them. Additionally, one Linux workstation will serve as a support for the HPC course, while the other will be used as a XEN server [10] for research purpose. The workstations are configured with remote access and the root access will be given to the group of the students that participate in this course.

After we have found the optimal solution to fulfill all of the laboratory purposes (research and courses needs), we need to find an appropriate operating systems and network configurations that should be installed and configured, which directly impact the performance and the security of the laboratory.

C. Network Configuration

The whole equipment of the laboratory is interconnected with the use of the Cisco switch, which is connected to the gateway of the laboratory, i.e the Cisco router. The network speed in the laboratory is 1 GbE.

The router and switch are configured with 4 VLAN networks, which enables segregation of whole network in smaller segments, because our plan is to eliminate the network broadcast and internal access between the two different cloud platforms and the other "student" workstations. Also, the router is configured with NAT/PAT and access control lists (ACL's) that enable the laboratory administrator to control the remote access, thus to mitigate the security risk of unauthorized access to laboratory resources.

Each laboratory workstation will be configured with static (private) IP address and in order to be accessed from outside of the laboratory. However, not all of the workstations can be accessed from outside. For example, just the cloud tier from both cloud platforms can be accessed by the administrators from outside of the laboratory. Other cloud nodes are configured to be passwordless accessed only from the appropriate cloud tier nodes. Static IP addressing of the workstations offers a quick and clean management of the laboratory. Administrators temporarily grant access to specific ports on the workstations as required by students, which could be accessed from outside the laboratory.

D. Workstation Roles

Three workstations that are dedicated as Eucalyptus cloud nodes, are installed with CentOS 6.5 and each of them runs a unique Eucalyptus cloud component, thus each workstation represents an appropriate tier of the Eucalyptus cloud platform.

Other three workstations, which are dedicated as OpenStack cloud nodes, are installed with Ubuntu Server 12.04.3 LTS and each workstation runs a unique OpenStack cloud component.

The last six workstations are dedicated as base for hosting VM instances by the Eucalyptus or OpenStack cloud platform, being controlled by one cloud platform at the moment. The purpose of this group of workstations is to scale the performance of one of the two cloud platforms at the moment to the purposes of the laboratory (instantiating VMs).

Mac Pro server is used as a local server (file, storage, database, and so on) and wi-fi spot.

V. Conclusion and Future Work

This paper presents a case study of practical transformation of a traditional faculty laboratory to state-of-the art online cloud-based laboratory. Also, it presents an optimal architecture (solution) that covers many laboratory requirements or purposes (research, faculty courses, projects and so on). In our case, the optimal architecture consists of deploying two most known open-source cloud platforms. Also, this laboratory acts not just as a IaaS platform, but also as a Platform as a Service (PaaS), because the laboratory offers networks, servers, storage, and other requirements that are needed for the students to work and host their projects. The laboratory can be used by many types of users from on-site or by distant access. For instance, young researchers (master or PhD students) could work on-site or remotely, and the students can work-on site while they have the laboratory exercises by the faculty courses.

In near feature our laboratory will be extended with additional hardware and will be improved in many directions. For example, we will greatly extend our cloud platforms clusters, create custom VM images for each faculty course with preinstalled software ready for work, create a bridge between the two cloud platforms and etc. With the extended cloud platforms we could easily handle more courses, projects and other unpredicted faculty activities of other KAs. Also, our future plan is to analyze and change if necessary the Eucalyptus and OpenStack cloud platforms with CloudStack or OpenNebula. The migration also will introduce new challenges such as migration of the existing VM images and volumes from the current cloud platforms to the new ones.

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