Implementing Telecommunication's Switching and Routing Laboratory Practices: Migration to a Distance Learning based Instruction

Dr. Rigoberto Chinchilla, Eastern Illinois University

Dr. Rigoberto Chinchilla: PhD in Integrated Engineering, (Electrical and Industrial), Ohio University. Is an Associate Professor of Applied Engineering and Technology at Eastern Illinois University (EIU) since 2004. His teaching and research interest include Quality Design, Biometrics and Computer Security and ethics, Automation and Telecommunications. Dr. Chinchilla has been a Fulbright Scholar and a United Nations Scholar, serves at numerous departmental and university committees at EIU and has been awarded several research grants in his career. Dr. Chinchilla is a book author and has published several peer reviewed technical papers during his tenure at EIU. rchinchilla@eiu.edu Tel: 2175818534

Mrs. Oyindamola O Idowu, Waukegan Schools District 60

Oyindamola Idowu, MSc. in Technology, Eastern Illinois University, is the current Network Administrator for Waukegan School District #60. She worked as Graduate Assistant in the Telecommunications Laboratory at Eastern Illinois University from Aug 2011 – May 2013. She has a B.Tech. degree in Computer Engineering from Ladoke Akintola University of Technology, Nigeria. Oyindamola is also a Cisco Certified Network Professional (CCNP) with research interests in Biometric and Network security.

Mr. Thomas C MacMullen, Eastern Illinois University

Thomas MacMullen, MS in Computer Technology, Eastern Illinois University, is a Systems Programmer in the Information Technology department of Eastern Illinois University (EIU) and is an adjunct instructor there as well. His research and teaching interests include Virtual Desktop Technologies, Green Technology Initiatives, and Programming Languages. He can be reached at tcmacmullen@eiu.edu

Implementing Telecommunication's Switching and Routing Laboratory Practices: Migration to a Distance Learning based Instruction

Abstract

The traditional learning environment laboratory practices, related to telecommunication laboratories, are aimed to learn to program and interconnect a variety of switches, routers, firewall appliances, VoIP phones and support equipment. These practices are typically pre-wired within our laboratory facilities and students are required to work within the facilities as part of their practical experience. The need to be physically present at pre-scheduled hours with an instructor, limits the possibilities of many non-traditional students wanting to take these courses. The need to design viable alternatives that allow students to access laboratory facilities remotely without losing most of the educational objectives, typically achieved in a face-to-face environment, is increasing by the day.

This paper describes a solution already implemented and tested in order to move a traditionally taught routing and switching telecommunication course, to ONLINE-based instruction. The design requires remote access authentication to the VMWare View system which is composed of three servers: The secure server, the composer server and the administrative server. These servers have been virtualized and reside on the hardware allocated for the project. The VMWare View system is housed in a cluster of eight Sun Server X6250 blades. Each blade serves as a VMWare ESX 5.0 host. Within the administrative server, a pool of virtual computers is created. Any student with internet access enrolled in the course can authenticate to the VMWare View secure server which checks them for password validity and for access authorization. Once access is granted, the user is assigned to a random virtual computer in the pool. Upon logging off, the virtual computer that the user was logged into is deleted and re-copied from the snapshot so that the next user who logs in to, it will get a clean copy and will not be able to access the previous user's data.

Once a student is granted access to a virtual machine it can first perform hundreds of simulations with virtual routers, switches, terminals and with all current telecommunication protocols within the virtual server environment. We recommend the use of either the NetSim® for CCNA V9 simulation software by Boson or the CCNA Routing and Switching Virtual Lab. Titanium Edition 3.0® by Wiley. Once the students get proficient with a simulated laboratory environment, which mimics the real set-up of the laboratory facilities, a specially created secure proxy-firewall network allows then to take control of the laboratory real facilities, which are pre-wired for the specific practice in place. Students then are allowed to manage and program real switches, routers, VoIP phones, firewall and perform laboratory practices as if they were present in the laboratory. In case they need assistance, instructors with remote access to the facilities can be reached online and assist the student in need.

Introduction

Traditional learning environment laboratory practices related to telecommunication laboratories are aimed to learn to program and interconnect a variety of switches, routers, firewall appliances, VoIP phones and support equipment. These practices are typically pre-wired within our laboratory facilities and students are required to work within the facilities as part of their practical experience. Enrollment maybe hindered because instructors typically require their students to be physically present in the laboratory facilities at a predetermined time. Students living far away from our facilities and those wanting to complete their education in an ONLINE fashion are limited by this traditional teaching modality. Laboratory facilities also stay idle for many hours when the students are not physically present limiting the student access to review practices and special projects. A university capable to provide 24/7 access to the laboratory facilities from any location will be perceived in the current environment as more student-friendly and efficiently managing laboratory facilities.

It is still customary, necessary and generally accepted with courses related to routing and switching (and telecommunications in general) that a heavy "hands on" component must be part of the educational process in order to improve not just the understanding of the subject but also student competences for the job market[1]. To change traditional courses, heavily loaded with hands on experience, to a distance learning format is one of the more difficult challenges for any educational institution especially in science, engineering and technology. Gregg[2] stressed that laboratory practices are as an important to a telecommunication and cyber security specialist as it is to a chemist or a biologist: "Although there are manuals that explain how different networking devices work in isolation or within a simple network architecture, but these manuals are inadequate to explain how networking devices will behave when they are part of a complex network. Only real experience with the equipment is able to closely replicate real-life situations and help the learner to develop troubleshooting skills."[2] In recent years, "internet accessible telecommunication laboratories are being researched theoretically with increased technicality and enthusiasm resulting in more published papers on the subject but little has been done to propose a full working implemented solution. Scholars are now interested in the development of remote computer network laboratories, virtual laboratories and powerful network simulation programs that closely mimic the operation of corporate computer networks".[3]

Different techniques and methods are being used by institutions in order to provide a different degree of learning experience to distance learners and at the same time reduce the cost of constant upgrades. Demonstration videos, remote access to physical laboratories, simulation software, and virtual laboratories with the aim of providing a level of satisfaction similar to face-to-face experience are constantly developed. Virtual laboratories and simulations came to the rescue of kinesthetic learning and provided a safe way of learning by doing. With virtual laboratory, the student can follow his/her imagination and explore a series of "what if" scenarios by changing input and learning from the different response of the system. Network simulators can also be customized to serve specific learning purposes in laboratory practices thereby creating a virtual laboratory. These simulators support various networking protocols such as TCP, UDP, IP, and wireless standards. Most commercially available network simulators are Graphic User Interface (GUI) driven while some are command line-based. Some examples include, NetSim, OPNET, Packet Tracer and CCNA Virtual Laboratory. When compared to the time required to create a complete test network and the associated cost of the required devices,

simulators are faster and cheaper. They also make it easier for researchers to test how a new protocol will behave in an existing network.

NetSim[4]: NetSim Network Simulator® is an application used to simulate Cisco Systems' networking hardware and software. It was designed specifically to the learning of Cisco IOS command structure. NetSim software includes a comprehensive laboratory menu containing of lessons and laboratory practices for routing protocols, Cisco devices, switching and topological design. Remote laboratories have helped to increase accessibility of networking laboratories and to reduce the cost of multiple equipment and constant upgrades. A study by Lahoud and Krichen[5] explained that "although remote laboratories were primarily designed for individual learners, they can be used for collaborative work among multiple learners to mimic a situation where two or more people manage a physical network. Some remote laboratories are used to completely replace laboratory exercise and at the same time combine both local and remote experiments".[6] The CCNA Routing and Switching Virtual Lab. Titanium Edition3.0® by Wiley also offers similar features to those of NetSim[7].

The remote laboratory design can be subdivided and conceptualized as five different projects working integrated:

- A network which connects all the laboratory components.
- A public access network capable to authenticate the World Wide Web users to a proxy server in order to distribute users (and their privileges) to single virtual machines. Including a firewall network internal infrastructure capable to route authenticated users to real laboratory facilities.
- The VMWare View system which is composed of three servers: The secure server, the composer server and the administrative server. These servers have been virtualized and reside on the hardware allocated for the project. The VMWare View system is housed on a cluster of eight Sun Server X6250 blades.
- The use of simulation software, including newly designed simulation practices
- The adaptation of the academic materials to the newly designed modality. (Laboratory guidelines, syllabi etc.)

This paper aims to explain details of the above projects, their integration and testing results as well as the general educative guidelines in the process of transforming a face-to-face course to an ONLINE delivered routing and switching course.

Networking Laboratory Design and Components

Currently the telecommunication laboratory at Eastern Illinois University is designed as depicted in Figure 1[8]. On the right side of Figure 1, Six CISCO® Routers are interconnected in a ring fashion style. These routers are called the "Internal Network" and are interconnected using dedicated serial links using the PPP protocol. Each router has its own Local Area Network with at least one computer connected using the Ethernet protocol. This configuration allows the students to be familiar with the routers' IOS, Serial and Ethernet ports, and the basic Static and dynamic routing programming. Neither the IP addresses nor the programming in general of the Internal Network routers are fixed. This is done on purpose to allow our students change their

configuration constantly upon the practices they are conducting. Students also configure access lists (ACL's) and learn the basics of configuring a router as a firewall. Practices with VLAN's and wireless access also complement the use of these six interconnected routers. Most practices related to the above subjects require no physical changes in the configuration (i.e. changing cable connections and or machines). The six routers in the ring configuration are CISCO® 1900 series routers. These routers allow our students to test modern application concepts like VPN's, VLAN's, Firewall deployments and Wireless VLANs[9].
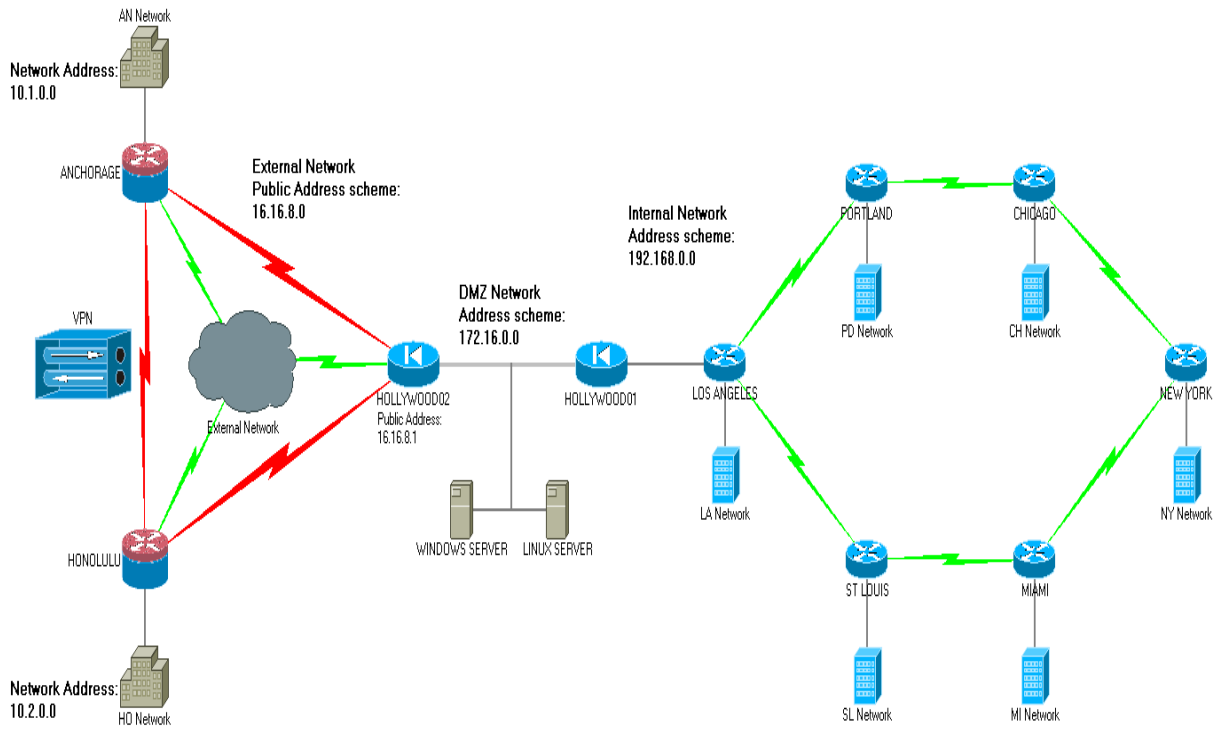

Figure 1: The Current Structure of the Telecommunications Laboratory[8]

In order to teach more advanced concepts about firewall architectures, server hardening and firewall programming, a Demilitarized Zone (DMZ) has been created using one of the "Internal Network" routers as a border router. Two firewall appliances (PIX models) create a demilitarized zone with two servers (Windows and UNIX). One of the PIX firewall appliances gives access to the "External Network" composed of two "remote" routers connected to a simulated cloud. The above laboratory configuration allows students and instructors to design at least two to three dozen different laboratory practices not only for undergraduate courses in networking but also to graduate courses in switching and routing as well as graduate courses in network security. Both remote networks also contain IP phones that are programmed to interconnect voice over IP applications between the routers of the External Network. The acquisition, development and fine tuning of this laboratory set-up took about two years and currently are fully functional for application regarding network defense techniques and telecommunication's switching and routing in general. Several more practices and equipment

additions to this network are planned to be incorporated in the near future related to subjects like internal security watchdogs and to simulate hacker attacks from the World Wide Web.

So far courses related to this laboratory have been either Face-to-Face or Hybrid (Internet plus Face-to-Face). The hybrid course design comes from the fact that students must show up for at least three full Saturdays (8a.m – 5p.m.) during the semester to perform laboratory practices and exams. The theoretical part is mostly covered using the ONLINE instruction application software Desire2learn® (D2L).

Public Access Network Design (PAND)

The PAND can be represented by three major blocks: Remote users, Authentication servers (housing the virtual laboratory simulators) and the Internal Network. This layout shields the user from the complexity of the system as represented in Figure 2[10]. The goal of the design is to allow students to perform networking experiments from remote locations with a high level of interaction with laboratory equipment. In addition to the existing laboratory devices an edge router, a firewall, distribution layer switches, and a virtual server were added to provide secure access, fast switching of traffic, authentication services and restricted access to other networks. A Virtual Local Area Network (VLAN) was created exclusively for the project to enforce logical segmentation.

Major Design Elements

The External Router is the first line of defense for packets arriving at the network. It analyzes incoming or outgoing packets and based on the information contained therein in order to discard or accept packets. The External Router uses the Border Gateway Protocol (BGP) to make routing decisions between the existing network infrastructure and traffic coming from the Internet. The Firewall in this design is a crucial component because it can implement defense-in-depth by restricting specific traffic just to VPN connections and by performing address and protocol filtering.

The distribution layer switches make quick and intelligent routing decisions ensuring that packets are routed efficiently and promptly to the destination. The Distribution layer switches forward segmented VLAN traffic to and from the access layer switches connected to the Telecommunications Laboratory. To ensure high speed forwarding, dedicated 10 Gigabits fiber optic trunks were used to pass VLAN traffic. The number of distribution layer switches as well as their logical arrangement depends on existing network infrastructure and needs.

The Virtual Server is housed in a cluster of eight Sun Server X6250 blades. Each blade serves as a VMWare ESX 5.5. This virtual server hosts the virtual laboratory software and also handles user authentication. Using Remote Desktop Protocol (RDP), remote users will authenticate into the server and will be able to wither use the Virtual Laboratory software or Proceed to the physical laboratory.

The Virtual server has two network cards like a bastion host. One card belongs to a public VLAN the other card belongs to the telecommunications laboratory private VLAN. The server is responsible for routing user sessions between VLANS. The use of VLANS and different physical network cards will accomplish the isolation of the laboratory network in our facilities from the existing network infrastructure. Once users are able to telnet to one router of the internal network, they can telnet to all other routers of the internal network without restrictions.
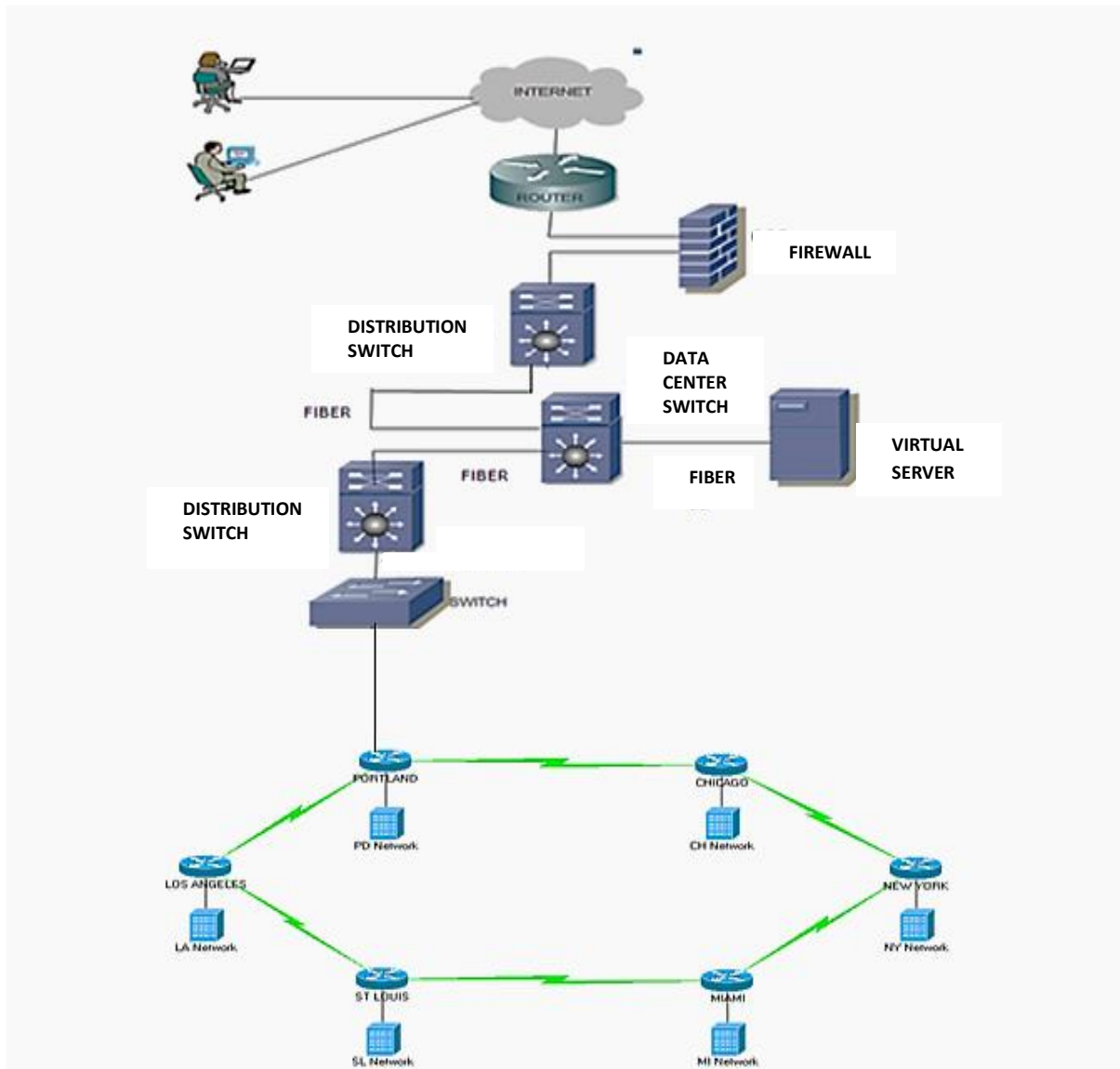
Figure 2: Internet Accessible Remote Laboratory Network Design[10]

Virtual Servers and Virtual Machines Design

The VMWare View system is composed of three critical servers: The secure server, the composer server and the administrative server. Each of these servers has been virtualized and resides on the hardware that we have allocated for the project. The VMWare View system is housed in a cluster of eight Sun Server X6250 blades. Each blade serves as a VMWare ESX 5.5 host. This maximizes the distribution of computing resources and allows for multiple failover points. In order to create machines that will be accessible to the students, an administrator must first log in to the VMWare View system via vCenter and create a master image. A master machine is a virtual computer that serves as a template for other machines. The administrator provides the specifications of the computer such as memory, hard drive space, the number of processors and cores and then installs the operating system and any other necessary software.

Once the administrator is satisfied that the master image fits the requirements, a data snapshot is taken of the master image and the computer is ready for cloning.

The administrator then logs in to the VMWare View administrative server and creates a pool. A pool is an allocation of computing resources that is made available to various groups of users. Creating a pool allows an administrator to specify which master image virtual computers will be built off of, how many virtual computers will be created, how the virtual computers will behave when logged off of or shut down and who will have the ability to log in to the virtual computers. After all the settings have been completed, the VMWare View administrative server passes the information to the VMWare View composer server in order to create the virtual computers. Figure 3[11] shows the conceptual view of the VMware system.
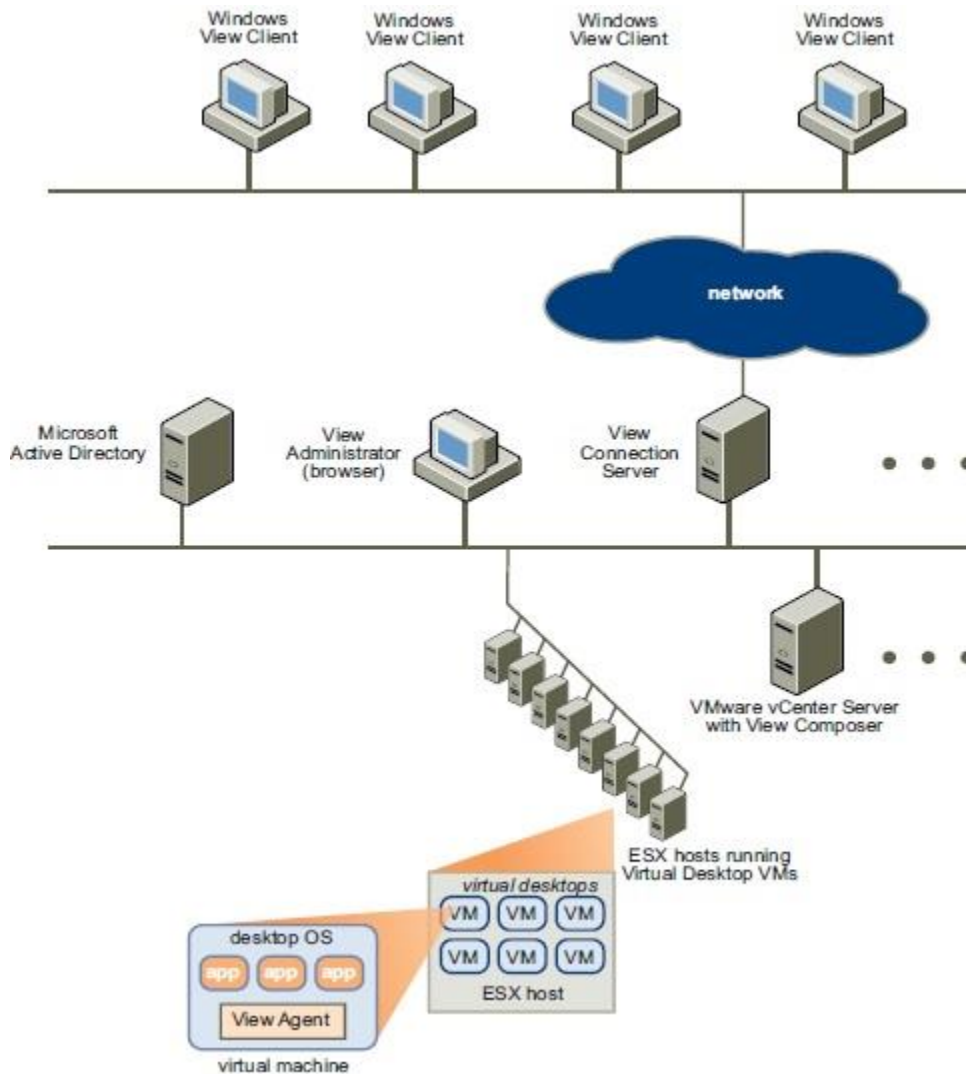

Figure 3: The Conceptual View of the VMware system.[11]

The VMWare View composer server creates multiple copies of the master computer using the data snapshot taken from the master computer and store them on the Sun Server X6250 blade. The process can take anywhere from 5 to 45 minutes. Once the virtual computers have

been created, users who have been given access to the pool will be able to reach the pool containing those computers via the VMWare Horizon View client. The client software can be downloaded by the user from a web interface located on the secure server. After downloading the client, the user will input the necessary information into the client software, including the user's unique user name and password in order to properly connect to the system. The VMWare Horizon View client passes user credentials to the VMWare View secure server which checks them for password validity and for access authorization. Once access is granted, the user is assigned to a random virtual computer in the pool. Information is transferred between the client and the server using the PC over IP protocol (PCoIP). Upon logging off, the virtual computer that the user was logged into will be deleted and re-copied from the snapshot so that the next user who logs in to it will get a clean copy and will not be able to access the previous user's data.

The Boson NETSIM® for CCNA V9 Network Simulator (NETSIM)

Once the student is authenticated to the VMWare View secure server, a virtual host machine containing the NETSIM simulator is assigned to them, initially 12 licenses are planned to be installed so an equal number of students can concurrently access the simulator. Access to the real facilities is independent of access to the simulator; therefore some students might be doing NETSIM simulations and others might just access the real equipment. The number of licenses is appropriate for the first year of use of the laboratory because just two graduate courses will be using the facilities in an ONLINE fashion (Each in a different semester). Eventually we will have to at least double the number of licenses in order to fulfill the need of all undergraduate and graduate courses we serve.

Among the reason why we adopted this software is for its Automatic lab-grading capabilities, it can also copy and paste the configurations directly to the real devices. Although is specifically designed to certify their users at the CISCO CCNA level, is flexible enough to use it without the goal of certification. It is our future goal to motivate our undergraduate and graduate students to take the CCENT and CCNA certification exams. Other features listed in the Boson Website are[11] the "Hands-on experience without the hardware, a Network Designer that supports 42 routers and 6 switches, up to 200 devices per network," and a patented Virtual Packet Technology that simulates real network traffic when packets are routed and switched through the simulated network. NETSIM also has the modularity concept when populating virtual WAN slots. There are a wide range of virtual cards that can be inserted in virtual slots as if were a real facility, a simulated telnet mode also allows students to control the console ports of the every virtual equipment. [12]

Once students get proficient with the simulated laboratory environment, which mimics the real set-up of the laboratory facilities, a specially created secure proxy-firewall network allows them to take control of the laboratory facilities, which are pre-wired for the specific practice in place. Students then are allowed to manage and program real switches, routers, VoIP phones, firewall and perform laboratory practices as if they were in the laboratory. The wired laboratory setup is typically fixed for two weeks, allowing students to perform the required laboratories with flexibility. In case they need assistance, instructors with remote access to laboratory facilities can be reached online at least 12 hours a day. Figure 4[13] shows a typical simulation laboratory network. An alternative is to use the CCNA Virtual Lab, Titanium Edition 3.0 Site License Edition® with very similar features to NETSIM Version 9®. Figure 5[10] shows a typical simulation for the laboratory network using the Virtual Lab. Product.
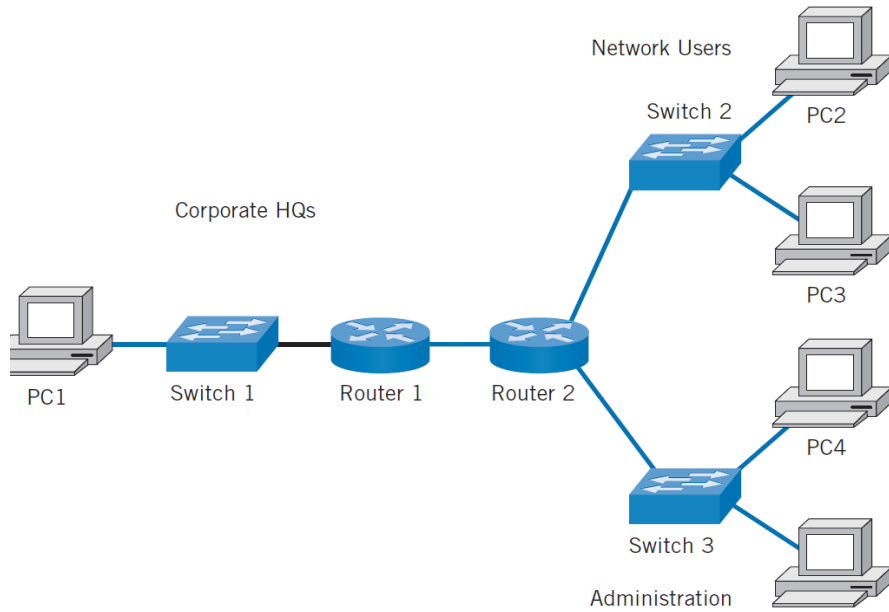
Figure 4: Sample of a NetSim LAB simulation [13]

Figure 5: Sample of a CCNA Virtual LAB simulation[10]

For our design we used both simulators because we wanted our students to be proficient with different simulators and because we have previous acquired licenses of both software simulators, saving us extra expenses. However we do not endorse one over the other, if an institution is implementing a similar solution one of the two will suffice in our opinion.

The ONLINE transition

This paper focuses on how to design online access to the Telecommunications Laboratory; however it may also serve as the foundation for achieving online modality for other technical courses. The general goal of this design is to allow students to perform networking experiments from remote locations with a high level of interaction with remote devices. We followed six general principles in every step of the way. In our criteria, the basic six design principles of an online laboratory are:

- Should be instructor independent. Students should be able to follow step by step procedures and complete assignments with minimum help from the Instructor or the Teaching Assistant.

- Should be simple and easy to use. Students should focus on the task and not get frustrated from the cumbersome technology behind the design.

- Should be engaging. Students should remain interested in the tasks at hand.

- Should have collaborative capabilities. Students can perform practices as part of a team as in real-life scenarios.

- Should be tailored to meet curriculum goals with quality. Laboratory practices should be carefully re-designed to achieve similar learning outcomes as traditional face-to-face experiments. This is probably the major time-consuming activity. The new guidelines will be under constant revision in order to fine tune them for at least two semesters until we feel comfortable with the results.

- Should have an interactive response time that mimics as much as possible the interaction with real equipment.

Conclusions and recommendations

This paper proposes a solution already implemented and tested in order to move a traditionally taught routing and switching telecommunication course, to an ONLINE based instruction. The laboratory has been tested randomly by professors and by former students. It will be tested formally in the spring semester of 2014 and ran at initially at 50% capacity in order to make adjustments, minor modifications and fine-tuning of the laboratory guidelines. Our ONLINE laboratory design is interactive, simple and easy to use, meet our curriculum goals and mimics as much as possible the face-to-face experience of previous courses.

We have tried our best to implement the above six design principles in the transition to an online based education. The laboratory guidelines have been redesigned so the students can have friendly and easy access to the equipment remotely as well can follow the instructions without

major intervention of the instructor. One of the major time-consuming tasks for the instructors will be to change the current face-to-face written laboratory guidelines to ones that are designed for the ONLINE access and programming of the laboratory equipment. The design of the new guidelines is a continuous process of fine-tuning until we are confident students do not need instructor help to complete their practices. Furthermore audiovisual aids should be designed in order to help them to use the virtual servers, the connection to the real laboratory facilities and to perform the simulations as planned. This will fulfill the first two design principles. We are also confident that the engaging part will be fulfilled when they realize no need for instruction intervention and the freedom to try new things within the laboratory. Most of the experiments are designed such that each student or each group of students is in charge of part of the whole routing and switching design programming project. They have to collaborate and communicate with others online until the project is a success. We are confident to reach the educational objectives as well or better in comparison with the hybrid and/or face-to-Face modalities. One of the advantages of the newly designed online laboratory is the access students will have not just to the equipment but to hundreds of simulations mimicking the existing equipment within the laboratory. In previous semesters, access to simulation software was only possible when they were present within the facilities, most of them scarcely did more simulations than the minimum required due to limitations in laboratory open hours. We hope to motivate them to do more simulations in homework assignments and special projects now that they have virtually unlimited access to the laboratory.

The solution has been cost-efficient because we have used the current telecommunications resources of the university network and the same laboratory resources we have within the laboratory, except by a modest investment in software simulation licenses in order to implement the design. Indeed unlimited access to the simulation software was not part of the face-to-face or Hybrid course offered in previous years and can be seen as a substantial enhancement of the telecommunication course's academic tools. The collaboration of the technical people in charge of the university network is a key component if any other institution wants to replicate what we have done. Without their expertise and collaboration it would be very difficult to build the access network appropriately. We believe that the final evaluation and fine-tuning of the laboratory guidelines will be complete within a year after we gather more data from our students regarding their experience with the course and laboratory practices.

References

[1] Yoo, S., & Horis, S. (2004, March). Remote access internetworking laboratory. ACM SIGCSE Bulletin, 36 (1).

[2] Gregg, M. (2008). Build your own security lab: A field guide for network testing. Indianapolis, IN: Wiley Publishing, Inc.

[3] Lawson, E. A., & Stackpole, W. (2006). Does a virtual networking laboratory result in similar student achievement and satisfaction? *Proceedings of the 2006 ACM Information.*

[4] *NetSim Network Simulator*. (2013). Retrieved from Boson: http://www.boson.com/netsim-cisco-network-simulator

[5] Lahoud, H. A., & Krichen, J. P. (2010). Networking labs in the online environment: Indicators of   success. Journal of Technology Studies , 36 (2), 31-40.

[6] Rojko, A., Zurcher, T., Hercog, D., & Stebler, R. (2011). Implementation of remote laboratories for industrial education.

[7] Tedder, William. CCNA Virtual Lab, Titanium Edition 3.0 Site License Edition. October 2012
189.- Euro2012. ISBN 978-1-118-53458-8 - John Wiley & Sons.

[8] Zetino, J. (2011). Design and evaluation of laboratory practices for a comprehensive networking curriculum (Master's thesis). Eastern Illinois University." pp.33.

[9] http://www.cisco.com/en/US/products/ps10538/ Last retrieved on December 2013

[10] Idowu, O. (2013). Internet Accessible Remote Real-Time Laboratory for Computer Networking Curriculum. pp.35 and pp. 31.

[11] http://www.vmware.com/pdf/view401_admin_guide.pdf Last retrieved on December 2013

[12]http://www.boson.com/network-simulator/ccna-200-120-cisco-network-simulator Last retrieved on December 2013.

[13] Boson, NetSim for CCNA Lab. Manual http://dc160.4shared.com/doc/u7ZNzkRK/preview.html Last retrieved December 2013.