Developing Web-based Interactive Teaching System for Core Network Technology Courses

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A R T I C L E I N F O	A B S T R A C T
	This paper presents an in-house created software application that emulates and virtualizes computer networking laboratory hardware and proprietary equipment on PCs and servers. A user friendly remote laboratory manage system is developed using .NET technology. Through the presented lab management system, the students are able to conduct more than 200 lab assignments covering 10 courses from both lower level routing and switching classes to upper level network management and security classes that demand a large amount of physical equipment and a great number of student lab contact hours prior to the emulated lab. This emulation solution eliminates our dependencies on expensive proprietary networking equipment. It also reduces the burden of system administration. This remote lab has been used and tested in three networking courses. The feedbacks show that the lab delivers similar or better lab experiences for the DE students while the lab construction and maintenance cost is reduced to the minimum.

1 Background

1.1 Education Based on VT

Virtual Technology (VT) allows multiple operating systems running on the same platform as virtual machines. It has been widely adopted by the modern industry. High end servers

and networking equipment are used to construct a consolidated system that improves manageability, enhances security, and greatly reduces cost.

The Information and Computer Technology (ICT) program of the East Carolina University has been pioneering in adopting VT for teaching computer networking, security, and system administration courses both in the undergraduate and postgraduate levels. During the past years, a state-of-the-art student remote computer lab was built on VT technology. Student can access to the lab 24/7 via the Internet. A tailored operating system image with software applications demanded by the student is automatically created during each lab use. One student reservation can have access to multiple operating systems through the use of VT-inside-of-VT technology. This feature is very important for computer networking and security major students who need a network of multiple operating systems to complete a lab assignment. The current remote-access computer lab can accommodate dozens of concurrent users.

This paper is an extended version of the author's conference presentation [1]. The creation of our lab using blade servers, VCL (Virtual Computing Lab), VMware, and Virtual Box was also well documented and published [2-6]. This paper will not significantly address the deployment of VT in education. Instead, it will focus on the development of a software application that employs VT and is tailored for a number of networking courses in the ICT program.

1.2 Emulating Proprietary Appliances

Most security, networking, and system administration courses highly rely on networking appliances for teaching the hands-on labs. Although the department has acquired IDS, firewalls, VPN appliances, IPphones, routers, and switches from various vendors in the past, the preference has been shifted to Cisco products. It is because first, Cisco is the industry leader for manufacturing networking and security hardware and software. Second, the ICT program has six courses that are tied to two Cisco certification programs – CCNA (Cisco Certified Network Associate) and CCNP (Cisco Certified Network Professional). Third, East Carolina University is a regional Cisco Networking Academy that oversees 14 local academies and trains their IT instructors. Most of these local academies are colleges and high schools.

To maintain a Cisco networking lab can be a challenge considering the rapid advancement of networking technology that requires constant software updates and hardware upgrades. The stagnant budget further limits our capacity to keep the lab equipment to a state-of-the-art level.

Software simulation has been a successful means in teaching Cisco networking courses.

Several simulators were tested by the ICT faculty including PacketTracer, LabSim, Boson, and Semsim. They are excellent substitutes of real Cisco equipment for teaching lower-level networking courses such as the two CCNA courses. However, the simulation software only builds a simplified abstract version of the operating system hosted by the appliances. It cannot be employed to teach higher level networking courses due to its limited functionalities.

VT makes emulation of Cisco appliances on PCs possible. The advantage of software emulation over simulation is that emulation allows the system memory to host the real and complete Cisco IOS (Internetwork Operating System) instead of trying to recreate a portion of it. It, therefore, provides the full functionalities of a real Cisco router, switch, VPN, and firewall. A small tool, named Dynamips [7], was identified for migrating Cisco IOS into computer memory. Once the IOS is loaded, the hosting computer is virtually transformed into a real Cisco appliance. VT further allows multiple instances of IOS's to be hosted within the same piece of physical memory. Along with the other operating systems, such as Linux and Windows hosted on the same physical memory through VMware or Virtualbox, a complex networking topology consisting of multiple hosts and networking devices can be emulated on one single PC. These operating systems communicate with each other through UDP/TCP ports on the hosting machine, emulating the physical Ethernet, token ring, and serial port connections.

Emulating proprietary Cisco appliances significantly reduced the cost and our dependency of real Cisco devices. The labs of our networking courses are taught by using the VT environment that is incorporated into our existing student remote-lab infrastructure where no physical Cisco equipment is required.

2 Software Development

2.1 Needs from Networking Courses

It is inconvenient to create a lab topology every time a lab is performed. The Dynamips software does not have a graphic interface and setting up the parameters for a specific lab can be confusing. Although some tools are developed to expedite the lab setup, none of them are designed for class teaching. Students still need to learn how to use these tools which are irrelevant to the contents of the actual labs.

To accommodate the lab needs of ten networking courses, the author developed a software application that is incorporated into a VCL image, named "ECU Cisco Lab". Students can access to this image through ECU VCL system as shown in Figure 1.
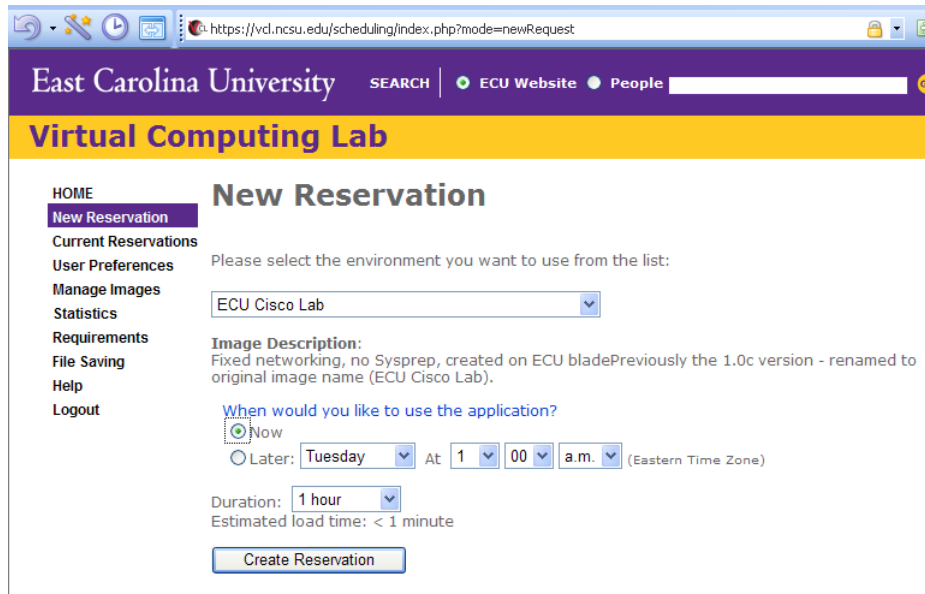
Figure 1: "ECU Cisco Lab" Image Reservation.

The ECU VCL system can allow a maximum of 40 concurrent accesses to the ECU Cisco Lab image. That means 40 students can reserve the lab by clicking the "Now" button at the same time and have the lab ready within one minute. If all the resources are taken and no image can be accessed at the moment, a student can reserve the lab for a future time, which rarely happens. Each reservation can be made up to 6 hours which is sufficient for the students to complete a lab exercise.

When the reserved image becomes ready, student can connect to this virtual machine through Windows RDP (Remote Desktop) connection. The IP address, username, and password of this virtual machine is displayed on a webpage and also sent to the student through email.

The "ECU Cisco Lab" is a Windows 2003 operating system virtual machine with all the software applications installed for teaching the networking courses including the "Dr. Li's Networking Studio", which is the major component of the networking lab. It is programmed by the author in C# language using MS Visual Studio. It is copyrighted in 2009 by ECU.

2.2 Interface Design

The interface design was based on the concept of clarity and functionality. The graphics and buttons provide visual guidance that leads students directly to the lab exercises. The main window, shown in Figure 2, appears when the user clicks the "Dr.Li's Networking Studio" icon on the desktop.

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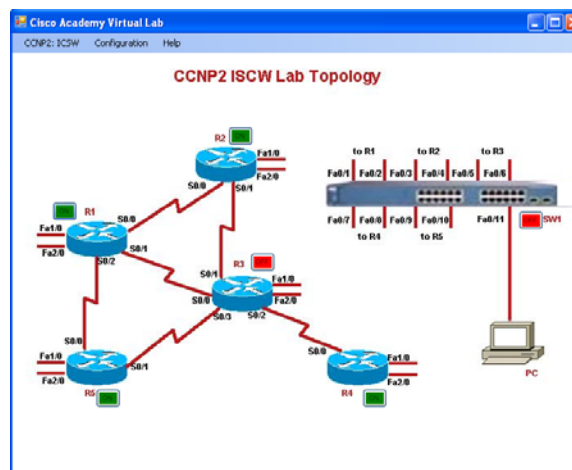**Figure 2:** The Main Window for 10 courses.

Figure 3: ICTN4251 Virtual Lab.

Figure 3 shows the sub-window of the network lab topology for ICTN4251 (Implement Secure Network), an upper-level network security class. Seven lab devices are shown on this topology including 5 routers, 1 switch, and 1 PC. The 5 routers have full-mesh connection through serial cables. They all have two Ethernet ports connected to the switch. A PC is connected to the switch via Ethernet cable as well. There are different lab setups with various devices for each course. Most of them involve routers, switches, firewalls, and PCs. Only the lab topology of ICTN4251 is shown here due to page limit.

The user can power on each device by clicking on the on/off buttons on the diagram. The central switch and Router 2 are turned on in Figure 2. The PC or Servers can be turned on through VMware. They are Linux and Windows operating systems hosted by the VMware virtual machines and bridged into "Dr. Li's Networking Studio" to construct a complete networking system.

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2.3 Operation

When a user clicks "configuration" button on the top menu, a dropdown list shows all the devices that can be configured through the system. For example, the user has options to configure Routers 1 to 5, a central switch, and a PC through the "configuration" menu in Figure 4. The configuration is preformed through reverse Telnet sessions to the hosting PC's loopback IP address. Unique TCP port number is assigned to each device to simulate console port connection.
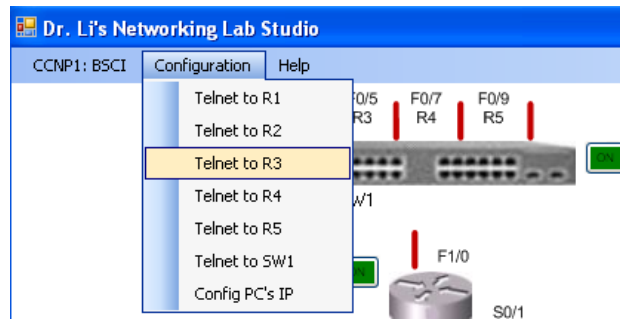

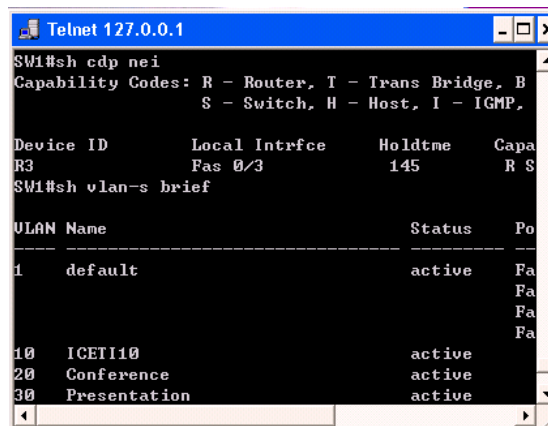**Figure 4:** Telnet to Lab Devices.

Figure 5: Device Configuration Windows.

The configuration windows look identical to the configuration windows used for the real physical equipment. The configuration window the Central Switch is shown in Figure 5. The output shows Router 3 is connected on the Fast Ethernet port 0/3 of the switch. The switch has three user defined VLANs, named "ICETI10", "Conference", and "Presentation".

Students are usually required to open multiple configuration windows simultaneously to configure the virtual networking devices, PCs, and servers. Students may not notice any differences between configuring virtual networking devices and the physical devices because the interfaces and configuration processes are identical. The only differences are the improved performance, faster lab connection, and enhanced lab provisioning from using the virtual lab.

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What is noteworthy is that all the presented devices are hosted virtually on one PC or a single server. No additional cost is needed if the "Cisco Network Lab" image is hosted on our existing VCL remote-lab infrastructure. The counterpart physical lab solution costs over $30,000 per pod.

Figure 6: The PDF Version of the Lab Manual.

Figure 7: The Video Lecture and Lab Instruction.

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2.4 Teaching Tools

As stated above, "Dr.Li's Network Studio" is closely tied to 10 networking courses. It not only provides the virtual lab equipment for the students to conduct lab exercises, but incorporates lab manuals and recorded videos of course lectures and lab demonstration into the package. Therefore, it is a complete DE teaching environment with both class lectures and lab exercises.

A PDF version of the lab manual is accessed through the first dropdown list on the main menu as shown in Figure 6. There are more than 200 labs that can be performed by using the software package.

The instruction button links the students to a pre-recorded video of a lecture and lab demonstration for each individual lab exercise. The videos were recorded in Windows Mediaplayer format by using Camtasia. The average length of the video is one hour. The videos review the key concepts that are covered by each lab and provide a step-by-step guidance for the students to do the lab along with. The videos are hosted on a secure web server maintained by ECU IT services. Figure 7. shows that a web browser is opened when the "instruction" button is clicked. The video is displayed within the browser.

3 Results

3.1 Assessments

Students were surveyed to evaluate the virtual lab software in two upper-level undergraduate and one graduate networking courses. These students had used the physical labs for their prerequisite courses before they were enrolled into the advanced networking classes. The surveys were conducted at the end of the semester. 87% of the students prefer the virtual lab over the physical lab for improved availability and ease of usage. 93% of the students agree that the instructional videos and the "Dr. Li's Networking Studio" software are very helpful for them to understand the course material and complete the lab exercises.

The user overall satisfaction of the virtual lab solution is 90.3% versus 58.3% for the physical lab. The result is statistically significant ($p < 0.05$ level) to reject the null hypothesis, indicating differences of the two lab teaching approaches.

Peer reviews were performed by faculty, who are teaching networking courses, from the same department of the author and other institutions. The responses are overwhelmingly positive.

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3.2 Comparison

When comparing the virtual learning environment created by this study with the traditional remote DE lab using physical equipment, the virtual lab is significantly superior in the following aspects.

Management and Maintenance. Once the image is created and deployed through a reservation system before the start of the semester, no more updates, cabling, and equipment maintenance is necessary.

Cost. The cost is reduced to the minimum considering no physical lab equipment is needed. The lab space and electricity usage are also reduced

Availability. 40 students can access to the lab simultaneously 24/7; while the physical lab only has two pods of equipment that allows a maximum of two students to use the lab at any given time.

Portability. The virtual solution makes the complete courses portable. Students are able to watch the lectures and conduct lab exercises anywhere there is an internet connection.

Synchronous teaching. The virtual lab allows instructors to login to the same virtual image a student is working on through VPN software such as RDP and VNC; so that instructors can monitor student activities and instruct the student to complete the lab. This synchronous approach has been used to evaluate student hands-on skills in real-time for two networking courses.

4 Conclusion

This study presents a software solution that emulates proprietary networking equipment, constructs a remotely accessible networking lab consisting of virtual security appliances, routing and switching devices, servers and PCs, teaches lectures and labs, and builds a both synchronous and asynchronous teaching environment. The presented software has been deployed through an existing online reservation system and used by 10 networking related courses. The student evaluation and peer review indicate significant performance improvement of the virtual lab over the physical lab.

The results from this study can be easily disseminated through Cisco Networking Academy program to thousands of networking programs nationwide.

5   Acknowledgement

6   References

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