A Reservation and Equipment Management System for Secure Hands-on Remote Labs for Information Technology Students

Lee Toderick¹, Tijjani Mohammed², Mohammad H. N. Tabrizi³

Abstract - Distance education programs in Information Technology (IT) suffer from several unique challenges. First, technology equipment like computers, routers, switches, and Information Security hardware is expensive and could easily consume a large portion of a department's annual budget. Second, suitable access to the equipment by students is often limited to normal faculty workdays, excluding evenings and weekends. Finally, adapting labs for delivery through any means other than the traditional classroom environment is extremely difficult in terms of resources, development time, and commitment from faculty and administrators. In this paper, the authors present an in-house solution that was developed to allow students to reserve computers, routers, and switches via the internet; conduct their hands-on exercises at their convenience, save/restore their configurations and exercises, and automatically restore the equipment to neutral state for the next user.

Index Terms - Distance Education, Hands-On Distance Learning, Online Learning, Online Labs, Remote Hands-On Labs, Secure Remote Labs.

INTRODUCTION

There is a significant push towards offering a considerable number of programs over the Internet [1]-[6]. This is partially due to the increasing demands for continuing education by working professionals, mobile military personnel, and home-bound adults needing higher education but are unable to physically attend schools due to personal or professional obligations.

Advances in computer and networking technologies, personal and wireless communication systems, along with declining costs of such items have accelerated the adoption of internet-based programs at a much higher rate than traditional distance education (DE) programs. As a result, there is significant activity among academic institutions as they capitalize on this enrolment-boosting opportunity by creating online courses and programs [1]-[6]. The bulk of these efforts, however, revolve around theory-based courses or those not needing control and manipulation of real equipment [8, 10].

As attractive as internet-based programs appear to be, colleges and universities are still wary about offering lab-intensive online courses. To be successful, however, technology and engineering programs require a balance of theory and application in order to help students grasp what would have otherwise been abstract concepts [4, 21]. For this reason, traditional lab-based programs in various fields of engineering and technology have wrestled with the issue of offering their curriculum online due to the significant amount of hands-on lab requirements [7]-[9].

To ensure good understanding of technical content, new programs are exploring various ways of providing meaningful experiences to online students. Several studies have documented the feasibility and effectiveness of online instruction for mixed audiences [7]-[9]. Successful laboratory experiences via the Internet have also been demonstrated by [13, 18, 19, and 24]. In [21] the authors successfully demonstrated the feasibility of conducting remote labs on networking equipment. In that study, students worked at preassigned laboratory time slots. The students also received their lab assignments after being properly authenticated upon login in.

While the success of online courses has been widely reported, efforts to offer “hands-on” courses with real equipment online have been met with mixed reactions among the academic community. The bulk of online lab experiences have been positive [7]-[24]. Additionally, students taking these courses were mostly prepared to trade minor inconveniences for the flexibility of remote labs. Others even consider online programs as a relatively inexpensive way to get an education. In few instances, however, some students rated remote hands-on experiences very low [22].

THE IT PROGRAM AT ECU

The Information and Computer Technology (ICT) program within the Department of Technology Systems, East Carolina University (ECU), offers graduate and undergraduate courses to both traditional, as well as online students. Both programs have significant laboratory components that provide equitable
hands-on experiences to the traditional and the online students. This paper will focus on the undergraduate ICT program that has three concentrations: Information Technology (ICT-IT), Computer Networking (ICT-CN), and Information Security (ICT-I Sec). The bulk of the courses within the ICT curriculum contain rigorous hands-on laboratory components.

In an effort to expand program offerings to online students, it was necessary to develop laboratory environments and experiences that were comparable to those of face-to-face students. Initial efforts centered on available commercial solutions, but that quickly became problematic due to equipment limitations, lack of flexibility, and expense. For these and other reasons, it became necessary to develop alternative means of delivering the lab portions of our courses.

In this paper, the authors describe some of the technologies used by the undergraduate ICT program to integrate a remote lab environment for both online and traditional delivery methods. This paper will also address common issues faced in the creation and use of remote labs, and how locally developed solutions can be implemented to maximize equipment usage while providing the online students with adequate lab times that fit their individual schedules.

**OUR APPROACH TO REMOTE LABS**

To address the issues stated above, we have developed several in-house solutions that allow secure remote access to the lab equipment without interfering with the university network or hindering student progress. To control access and availability of resources, a reservation and equipment management system was developed. As a result of these efforts, students connect to the remote labs securely, and conduct a variety of lab experiments including installing and configuring network operating systems, Web servers, FTP servers, Mail servers; developing and deploying dynamic content; deploying web authoring tools; and controlling traffic using routers, switches, firewalls, etc. These solutions also allow students to work with flexible topologies, work at their selected times, and automatically scrub and restore shared equipment to neutral state(s) for the next user(s).

The successful implementation of our remote lab is the result of significant innovation, testing, refinement, and student feedback. The solution uses a combination of hardware and software. The actual control application is comprised of Linux bash scripts that are supported on a Linux Red Hat operating system, and are routinely executed during students’ login to the lab and at the completion of the reservation. The hardware consists of several items of control equipment such as network switches and power distribution units. A detailed description of the control software is presented later in this paper.

The success of remote lab experiences is measured through student learning. The overall goal of the remote lab is for online student learning to be as effective, as or even better than–the traditional version. It is the student discovery and learning experience, not merely convenience that makes remote labs so effective. Our remote lab model can be characterized by the following attributes, which should be considered at the minimum to provide accessibility, suitability, and security:

- A restriction device such as a firewall, which only permits registered students access to the remote lab. The restriction device must also permit only authorized network traffic egress from the lab.
- A Virtual Private Network (VPN) device, which encrypts the conversation between the student and the firewall as it passes across the Internet or other non-secure networks.
- A reservation system that permits the student to access remote lab equipment without any conflict from other students. That is, a student should be able to use the equipment without other student interference. Additionally, the student should be able to make equipment reservations at least one week in advance. This aids student planning and prevents equipment congestion and unnecessary equipment slack time.
- A well-defined design that permits faculty to easily add or remove hardware components without requiring major lab modifications. Further, the design should permit logical reconfiguration by the student that is restored to a default condition when the reservation has expired.
- Automatic restoration of the equipment to some pre-defined, default, state after a reservation has expired.
- A mechanism that permits the student to save their work and/or restore incomplete work.
- Utilizes minimal commercial hardware or licensed software, thus cost effective.

The remote lab resides within the campus network domain, which is firewall’d from the Internet as shown in Figure 1. Specifically, only network traffic originating from the outside with Transport Control Protocol (TCP) or User Datagram Protocol (UDP) well-known ports [14] up to 1023 are permitted through the University firewall. Therefore, there is a modicum of filtering before external traffic reaches the remote lab portal. For institutions without an outer firewall, a similar configuration can be used to separate the remote lab portal from the Internet.

![Figure 1. Overview of permitted traffic.](image-url)
Several control devices are used to provide connectivity and control:
- Power Distribution Unit (PDU)- controls AC power to the Cisco routers, enabling restoration scripts to erase a router’s configuration after a reservation is finished.
- Cisco Remote Access Server (RAS)- provides reverse telnet connectivity for the student between the Remote Lab Portal and the router. This connection is also used to save a router’s configuration and reload the Cisco IOS (when necessary).
- Control switch- maintains a LAN connection between the pod devices and the Remote Lab Portal. Through the use of VLANs, these connections can be modified by control scripts and returned to a default condition when the reservation is finished.
- Remote Lab Portal- contains two databases that are used by control scripts, and contain detailed information about each item of lab equipment used. Table 1 shows a partial output of database deviceparm and database hardwaredb:

Once the student’s TCP connection is established, the student authenticates to the remote lab and the reservation Main Menu script is displayed. The student never has access to the command prompt on the Remote Lab Portal, instead using menus to access equipment. Figure 5 shows the main menu for a student without a reservation, and Figure 6 shows the main menu for a student with a reservation. A reservation can be made or deleted by selecting the ‘s’ menu option and following the appropriate menus. A reservation can be made up to one week in advance, can be between one and six hours in duration. Students are not permitted to overlap their own reservation, but could, technically, make four, six-hour reservations. While no student has abused his or her lab time, an occasional email has been sent to students who fail to keep their reservation, but could, technically, make four, six-hour reservations. While no student has abused his or her lab time, an occasional email has been sent to students who fail to keep a reservation. The motto “take all you want, use all you take” has worked well in the eighteen months the remote lab has been active.

Session S3F

FIGURE 4. SAMPLE CONTROL TOPOLOGY FOR A SINGLE POD

Figure 4 shows the control topology for a single pod.

Figure 2 shows how the firewall rules are applied using IPTables, and Figure 3 shows the results of the applied rules.

FIGURE 3. PARTIAL TRANSCRIPT OF THE FIREWALL WITH RULES

The remote lab portal firewall permits only specific, defined traffic. The default behavior for the firewall is to deny all traffic. Then, rules are applied to only permit TCP port 22 (SSH) new or established traffic ingress and only TCP established traffic egress. Figure 2 shows how the firewall rules are applied using IPTables, and Figure 3 shows the results of the applied rules.

FIGURE 2. PARTIAL TRANSCRIPT OF IP-TABLES

Once the student’s TCP connection is established, the student authenticates to the remote lab and the reservation Main Menu script is displayed. The student never has access to the command prompt on the Remote Lab Portal, instead using menus to access equipment. Figure 5 shows the main menu for a student without a reservation, and Figure 6 shows the main menu for a student with a reservation. A reservation can be made or deleted by selecting the ‘s’ menu option and following the appropriate menus. A reservation can be made up to one week in advance, can be between one and six hours in duration. Students are not permitted to overlap their own reservation, but could, technically, make four, six-hour reservations. While no student has abused his or her lab time, an occasional email has been sent to students who fail to keep a reservation. The motto “take all you want, use all you take” has worked well in the eighteen months the remote lab has been active.

FIGURE 4. SAMPLE CONTROL TOPOLOGY FOR A SINGLE POD

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Lab equipment is organized into pods. A student makes a reservation for a single pod. Each pod consists of computers and networking equipment that students configure in order to complete the experiments and case studies. Up to six pods can be created and populated with equipment. Currently we have four active pods for two advanced networking classes, and a fifth pod for use by the traditional networking classes when the physical labs are closed at night or over weekends and holidays. A typical pod topology that consists of five Cisco Routers and two workstations is shown in Figure 7.

It is important to note that the topology shown in Figure 7 is not the only configuration that can be designed, or must contain only the equipment shown. For example, in Spring, 2005, we will add an information security pod that consists of three Cisco Pix 515Es, three Cisco routers, and five workstations. Another pod configuration consists of five Cisco switches, three Cisco routers, and five workstations. Up to six pods can be supported by one remote lab at this time. Table 2 shows the equipment currently available on each pod:

<table>
<thead>
<tr>
<th>Pod(s)</th>
<th>Equipment Supported</th>
</tr>
</thead>
</table>
| 1, 2, 3| Cisco 2600 router - Qty 4  
Cisco 2500 router - Qty 1  
Linux workstation - Qty 2 |
| 4     | Cisco 2600 router - Qty 3  
Cisco 2950 catalyst switch - Qty 2  
Cisco 3550 catalyst Layer 3 switch - Qty 3 |
| 5     | Cisco 2600 router - Qty 3  
Cisco 2950 catalyst switch - Qty 2  
Cisco 3550 catalyst switch - Qty 1 |

The following events occur when a student begins a lab session:

- A monitoring script is executed that routinely checks for the end of the reservation. Even if the student logs out of the remote lab portal, the equipment is not restored until the end of the reservation.
- As each Cisco device is accessed by the student, the device is logged for restoration.
- Approximately 15 minutes prior to the end of the reservation, a warning message is displayed on the menu screen that notifies the student that the reservation end is near. Three one-minute warnings, 10 seconds apart, are also displayed.
- At 10 minutes before the end of the reservation, the student is disconnected from any active connections. In turn, each Cisco device that was used by the student is accessed by a script that makes a backup of the
configuration. After the backup is finished, the device is restored to its default condition. This continues until all used devices have been backed up and restored.

- If the student has logged out, the monitoring script terminates.

When the student next logs in, he/she has the choice to either permanently save or delete the backup configurations.

One exciting prospect for the remote lab application is in the formation of partnerships with other Universities and Community Colleges. It is envisioned that a centralized Remote Lab Portal will reside at our University, and decentralized Remote Lab Portals will be made available to partnered institutions. When a reservation is requested that cannot be satisfied by the local Portal, an automatic query will be sent to the central Portal for resolution. If equipment is available at the central site, the reservation will be made. An additional scenario entails the central Portal querying other local Portals for a reservation.

**IMPACT OF THE REMOTE LABS**

As stated earlier, the success of remote lab experiences is measured through student learning. The overall goal of the remote lab is for online student learning to be as effective, as or even better than traditional lab learning. To assess the effectiveness of the remote labs, the students were surveyed to determine their perceptions relative to the adequacy and usefulness of the remote labs. A total of 33 students completed the survey, and their responses are summarized in Table 3.

**Table 3. Summary of Student Survey Responses**

<table>
<thead>
<tr>
<th>Question/statement</th>
<th>SA</th>
<th>A</th>
<th>DA</th>
<th>Total SA and A</th>
</tr>
</thead>
<tbody>
<tr>
<td>I was able to use the remote lab to complete my assignments</td>
<td>52%</td>
<td>39%</td>
<td>6%</td>
<td>91%</td>
</tr>
<tr>
<td>The remote lab was easy to navigate</td>
<td>30%</td>
<td>61%</td>
<td>9%</td>
<td>91%</td>
</tr>
<tr>
<td>It was easy to make a reservation for a remote lab POD</td>
<td>39%</td>
<td>58%</td>
<td>3%</td>
<td>97%</td>
</tr>
<tr>
<td>There were sufficient open reservation times to fit my schedule</td>
<td>18%</td>
<td>70%</td>
<td>12%</td>
<td>86%</td>
</tr>
<tr>
<td>The remote lab POD equipment was easy to access and to configure</td>
<td>18%</td>
<td>73%</td>
<td>6%</td>
<td>91%</td>
</tr>
<tr>
<td>Performing the labs helped my understanding of the material</td>
<td>30%</td>
<td>67%</td>
<td>3%</td>
<td>97%</td>
</tr>
</tbody>
</table>

Legend: SA=strongly agree, A=agree, DA=disagree, SD=Strongly Disagree*, and N/A=not applicable*.

A majority of the students indicated satisfaction with the remote lab environment. Part of the problem with the sufficiency of reservation times have been attributed to the fact the typical class sizes are set at 24 students, but in this case, the enrollment grew to a whopping 72 students! Despite this unexpected growth, it can be concluded that our remote lab successfully accommodated our DE students and afforded them an opportunity to conduct hands-on exercises at their convenience.

**CONCLUSION AND FUTURE WORK**

Using technology to provide a remote lab experience for the DE student has demonstrable benefits. The remote lab is an efficient use of scarce equipment and resources, providing the IT program with an alternative to traditional classroom labs. For the student, remote lab convenience is only one positive outcome, dwarfed by the experience and discovery gained when more time can be spent learning.

In some of the reviewed cases, students only receive the specific lab assignments after they have logged on to the network and then use the remaining time to complete the assignment. This method limits the amount of time spent on preparation, dialog, and exploration of alternate solutions to the same problem. In our remote lab implementation, students receive assignments in advance, develop their solutions prior to login on the network, and have abundance of lead time to consult with team members when needed. This vital step enables them to prepare well in advance prior to getting on the network, which in turn saves valuable time and resources. Additionally, our solution allows the students and/or the instructors to preload configurations, or those that have been saved from prior exercises or incomplete assignments, complete the work, implement and test the solution, and then save or submit revisions.

Other reviewed solutions were found wanting due to instructor involvement in scheduling lab times among the students. This method imposes additional overhead for the instructors and/or the students in terms of efforts needed from both parties in ensuring that the needed timeslot is assigned to the student. Our solution allows the students to make their own reservations to access the lab at their convenience. This feature has been found to be quite useful by both the students and instructors.

Our development of the remote lab was necessitated by the fact that current commercial solutions for remote labs are either too expensive, have inflexible topologies, or fail to meet the rigorous hands-on requirements of advanced internetworking courses. Today, our students can successfully conduct hands-on experiments with various network operating systems, advanced routing and switching equipment. Assessment and feedback results indicate comparable level of performance and satisfaction among the DE and on-campus students.

Future implementations of remote lab technology can be used to form partnerships with other education institutions in terms of sharing equipment or other resources remotely. These partnerships can strengthen programs and collaboration among faculty and the Departments involved. We intend to explore this opportunity to the fullest extent.
REFERENCES


