Remotely Accessible Computer Network Laboratory with Hands-on Experience

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Abstract— This paper presents the design and evaluation of a remotely accessible and platform-independent computer network laboratory. We have integrated two network standards namely IPKVM and VLAN to create a flexible and expandable laboratory system for remote students. Students located at remote sites were able to seamlessly conduct hands-on experiments and collaborate with their classmates. A survey was conducted among the students who enrolled in the "Introduction to Computer Networks laboratory" course at Illinois Institute of Technology. The results show that students can complete the lab experiments efficiently, and the remote framework does not impose any barrier in conducting experiments and consequently does not degrade the quality of their education. The system developed in our institution can be used for other laboratory courses such as computer networking security and system administration.

I. INTRODUCTION

Remote access technologies are receiving increasing interest in last few years in several industries and research laboratories. Remote access technology is among the hot topics in the literature since it provides the benefit to the corporations in respect to economy as well as administration. Utilizing the remote access technologies provides saving in transportations and administration of the devices from the remote locations. There are several applications, which benefit the remote access technologies in industry such as remote-operation [1], remote-monitor [2] and remote-control systems [3]. Remote access has also been employed in medical procedures and healthcare applications. One of the biggest challenges that the healthcare industry needs to deal with is to enhance healthcare and monitor with new technologies to reduce the costs. In addition, academia and research laboratories exploit the remote accessibility feature in e-learning and e-class paradigm for cost efficiency as well as providing education facility to off-campus students. While industry and healthcare corporations tend to favor the proprietary solutions due to technical support provided by the third-party vendors, academia, on the other hand, aims to apply the notion of open source technology. This helps academia to develop and update their own systems according to their needs. Specifically, e-learning has received so much attention within the last decade in university environments. E-learning facilitates the process of education to students by incorporating the remote access feature via the Internet. Even though online education has almost become ubiquitous in the academia for lecture-only courses, a few research works have utilized the merits to deploy the remote laboratory program due to necessity of regular attendance to complete the lab experiments [4], [5], [6].

In this paper, we propose a comprehensive framework for remote access to the laboratory instruments for hands-on experimentations. We specifically deployed our framework by implementing it in our computer network laboratory course. Our platform creates additional opportunities for students to access the laboratory equipment and to conduct the hands-on experiments remotely. Furthermore, the design of this lab follows industry practices, which students are likely to experience in their careers. Most remote access technologies in academia as well as the industry are based on a particular vendor hardware or software and do not support open source. Nevertheless, our approach does not depend on a specific vendor or proprietary technology.

There are three main features, which distinguish our work from others. First, our platform is independent of any third-party proprietary solution. Second, our platform gives the students a true hands-on experience to access real devices. It means students get opportunity to access actual network peripherals without emulating the environment by simulation tools. Finally, our framework is not specific to a single area and could be utilized at diverse environment such as medical, academia and industry. This paper describes both the technical and procedural changes needed to support remote access for a laboratory course in computer networking. In Section II, we briefly describe the recent work on the remote lab research in last few years. In Sections III and IV we describe in detail the design of our remote access framework. We specifically show how this framework will be implemented in a real life scenario. In Section V, student feedback is examined and the result of the survey is analyzed. Conclusion is presented in Section VI.

II. RELATED WORK

Recently, there has been several research works toward study and implementation of remote access technology in diverse applications. Accessing the remote system was initially deployed and used at the industry to monitor the control systems remotely by system administrators [7]. In these systems, several performance parameters of the remote system are sampled and sent via the Internet to the client side. The connection between devices was mostly based on low rate data links like ISDN. Later, due to improvement on the software engineering and increasing performance of Internet speed, the industries could

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also control the remote system parameters. Wireless Sensor Network [8] is the advanced development of the monitoring and controlling systems in the industry. Healthcare system is another main subject which takes advantage of remote access technology in order to facilitate the medical procedures and reduce the healthcare cost where doctors are able to visit their patients remotely and surgeons are able to conduct or supervise a surgery from a remote location [9]. One of the key applications in using the remote access networks is in the academia. The need to deliver the educational materials such as text, video, audio, etc. to the student across the Internet in the remote location is the moving drive. Several schools have already deployed the e-learning as part of their curriculum. Nevertheless, the remote laboratory in engineering education is relatively new technology and only a few implementations can be found on the deployment of the remote laboratory feature in engineering departments. Reference [10] depicts one of the early works where the remote access feature was utilized for purpose of the education in the laboratory. They implemented a platform by which students are able to connect and control the electrical devices via a 56K line data. Later, Schmid [11] used a simulator to design a virtual reality experience for mechanic students to learn the control system devices. Recently, [12] used the LABVIEW platform to simulate the operation of the electrical devices for the remote students. Most of these papers use the simulation approach to enable remote accessibility of lab devices by students. On the contrary to the above mentioned works, this paper demonstrates an efficient framework wherein the users are provided with the access to real networking devices in the lab. Consequently, this framework reinforces the learning process through hands-on experiments carried out in a flexible off-campus environment.

III. Laboratory Architecture

We implemented our remote access framework in the "*Introduction to Computer Networks laboratory*" course. This is a senior-level course provided by the Electrical and Computer Engineering Department at Illinois Institute of Technology. The main goal of this laboratory class is to provide students with a basic understanding of networking concepts with specific emphasis on different aspects of the Physical and Data-link Layers of the Open Systems Interconnection (OSI) Model. A primary goal of this course is to teach students how to deploy several network design experiments using different network devices. This course consists of several lab experiments where students learn how to configure and debug networking equipment as well as understanding the computer networking concepts. The laboratory experiments start with a preliminary introduction to the networking equipment and the remote access interfacing features. Then, fundamental concepts including bridge, router and routing protocols (for example, RIP and OSPF) will be examined.

Users are divided into several groups, and each group works independently on their experiments. Groups can have several members. Each group of users is equipped with a collection of several workstations, routers, switches and patch panels.
Table I shows the list of equipment assigned to each group.

Table I. Network Devices in a Work-Group

Devices	Count
Dell Poweredge workstations	6
Cisco Routers 3600 series	3
Cisco Managed switch 24 ports	1
IPKVM OpenGear	1

We have placed all networking equipments inside the rack as shown in Figure 1.

Figure 1. Computer Network Laboratory Server Rack

Furthermore, each group is assigned a device called Keyboard/Video/ Mouse (KVM) which on one side is connected to the network devices and on the other side to a single user terminal. Network equipment allocated to a group is accessible through KVM via this single user terminal in the laboratory. By this arrangement we utilized KVM to provide students the capability to access all devices from the user terminal in order to manage and switch between different workstations. Each lab experiment is composed of two basic tasks:

1) To create a network topology according to experiment manual
2) To configure the network devices using networking commands by using Linux and Cisco Internetwork Operating System (IOS) operating systems according to the lab instructions.

Students can accomplish task 1, the network topology, by connecting the network devices together with cables inside the patch panel in the rack. Students use KVM to interface with network devices where task 2 can be completed using configuration software to switch between different workstations during testing and troubleshooting phases. A major goal of the lab is to provide hands-on experience with common industry network equipment.

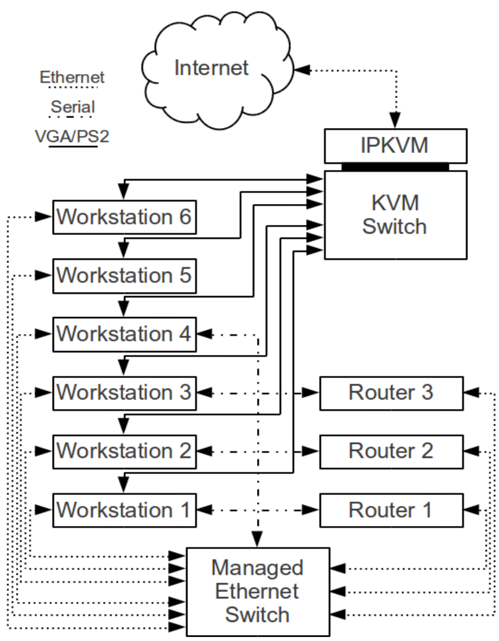

Figure 2. Block Diagram of a Work-Group

IV. REMOTE ACCESS TECHNIQUE

In previous section, we described the original laboratory framework which does not support remote access for the students. This frame work needs to be modified in order to make the remote accessibility possible for the students. In order to achieve that, the two tasks discussed in the previous section needs some adjustment. Several techniques in the industry and academic literature were investigated. Interestingly, the current network technology standards which originally were designed for other purposes are appropriate to solve this problem. We integrated two technologies (IPKVM and VLAN) to tackle the problem.

There exist many methods to replace KVM and provide the out-of-band graphical access to the network devices from a remote location. The most commonly used methods are Intelligent Platform Management Interface (IPMI) [13], Advanced Management Technology (AMT) and KVM over IP (IPKVM) technologies. Since both AMT and IPMI must be supplied by the third-party vendors, they are not suitable for our purpose. Additionally, IPMI and AMT techniques are accessible from the host which may allow students to obtain access to the campus network from within the lab environment. As the networking lab does not have authorization to connect to the campus LAN, it would be inadvisable to use these technologies in this environment. Another solution is IPKVM. This device is an improved version of KVM explained in previous section. Since it operates in 3rd layer of OSI model, it is accessible from anywhere in the internet using IP address. Furthermore, it provides the security requirements by disallowing the user to bridge the laboratory environment to the campus Intranet. Therefore, remote students are able to connect to the IPKVM and interface to other network devices.

Designing the network topology (task 1) in the original framework discussed in previous section requires students to attend the class and use physical cables and patch panel. In order to replace this procedure, we need to seek a technique which allows students to manage the connectivity of network equipment at layer 2 of OSI remotely and by means of software configuration. One of the few technologies suitable for this purpose is Virtual LANs (VLAN). VLAN provides the layer 2 isolation using the concept of a VLAN tag. Ports of a managed switch can be separated into several VLANs called "VLAN groups". Each VLAN group has a separate broadcast domain. It means, devices (workstations and routers) which are members of a VLAN group can only communicate with other members of the same group. As a packet enters the ingress queue of the switch, a VLAN tag is added to the front of the packet as defined in the IEEE 802.1q [14] standard. This tag eventually will be processed by the switch to determine the valid egress ports where the packet can be transmitted. After connecting to the IPKVM, students switch the interface to the environment of managed switch and configure the VLANs according to the given network topology in the manual. Therefore, the managed switch completely alleviates the need to use patch panels and cables. In other words, remote students only need to configure the VLAN membership inside the switch to implement the network topology of the experiment. Note that, VLAN is IEEE standard and has been implemented successfully in different third-party managed switches and is not proprietary of a specific vendor.

Since the main medium to connect to the remote servers is the Internet, we need to shape our protocols based on 3rd layer of OSI. As mentioned previously, IPKVM is a 3rd layer device and therefore is accessible across the Internet. IPKVMs provide the remote access to keyboard/video and mouse of several workstations using an integrated graphical interface. After connecting to the IPKVM, users may access to the managed switch and utilize the VLAN technology in order to design the network topology mentioned in the procedure. Figure 2 shows the connectivity between the switches/routers and workstations with the IPKVM in a remote lab group.

For this lab, it is required to give students root access to the Linux workstations in order to configure networking software. While it may be possible to utilize the *sudo* tool to allow more granular root access to students, it was found that the common approach used by industry is to provide root access. However, this leads to a situation where the constant changes by students create diverging configurations; thus, generating unnecessary complications for the teaching assistant which makes troubleshooting much more tedious.

By allowing the root access to students, the only way to guarantee a consistent experience on each of the workstations is through re-imaging. Re-imaging configures the workstations such during the boot-up phase the workstations can reload their default configuration from a specific server. For re-imaging, two boot methods, namely Pre-Execution Boot (PXE) and Kickstart are used. Pre-Execution boot is a boot method supported by most modern computers where the machine boots from a binary supplied through the network interface. For Linux, there is a network bootable binary named PXELinux which has the ability to load the Scientific Linux 6 installer. Using an option supplied to the installer, the installer downloads a Kickstart file. A Kickstart file describes how to install the workstation from scratch automatically. Once the installation is completed, the machine is completely re-imaged and the workstation is ready for use. Therefore, we can maintain the integrity of the system even though it is under several administrative changes during the experiments. This process is demonstrated in the Figure 3 below:

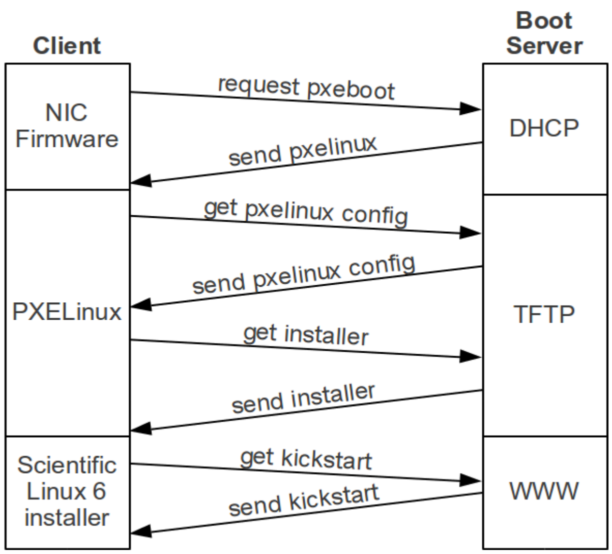

Figure 3. Application Interactions During PXE Boot

In our remote framework, students can connect to the IPKVM using a Java client program on the remote site. This program provides a graphical interface to the screen of remote workstations. Users are able to switch between several workstations and complete the configuration tasks inside the Java program. The interface has the compression and scaling options to make the environment flexible and user-friendly for remote students. We emphasize that this is a direct control access of the remote users to the workstations at the laboratory and no simulation tool is being utilized. The activities of a student inside this program can be seen concurrently by all other group members.

Note that, this method has been designed to be used by all students whether they are on-campus or off-campus. Therefore, there will be no shortcoming with the remote students compare to on-campus users. The snapshot of the Java program is shown in Figure 4. This figure displays specific tabs for each workstation.

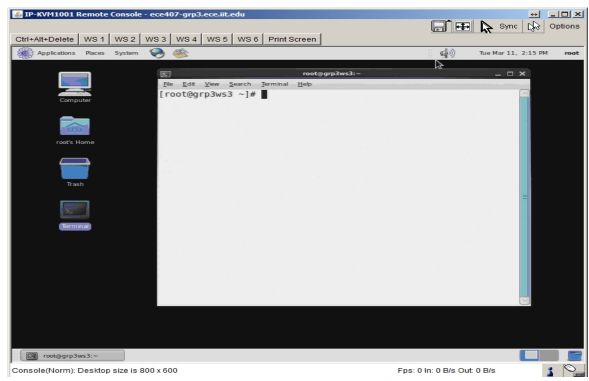

Figure 4. IPKVM Remote Interface

A. *User Collaboration*

Each group consists of several students, and therefore, a collaboration tool is required to arrange the cooperation among several remote users. For this purpose, we decided to use the CourseSites Live tool from the CourseSites[15] online education center. CourseSites Live has two advantages for student use. First, it helps them to collaborate with each other and discuss the issues encounter during the experiment. Second, they can have bidirectional interaction with the instructor and to seek assistance while conducting the experiments. This software tool is a java-based application and provides the video, audio and text communications capability. Instructor can put the remote students within each group into private chat room. Figure 5 shows a snapshot of CourseSites Live collaboration environment.

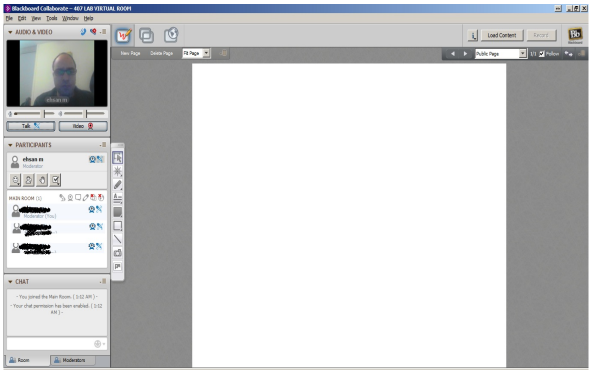

Figure 5. CourseSites Live Collaboration Tool

V. Performance Evaluation

In order to evaluate the performance of our framework, we implemented and tested our platform in the Electrical Engineering Department of Illinois Institute of Technology during the academic year of 2013, for the course titled "*Introduction to Computer Networks with laboratory*", . A total of 40 students are registered in the course. First session of the class is devoted to teaching the fundamentals of the remote lab. The Introduction material was also available online. Each group of students is required to conduct several lab experiments during the semester. After finishing each experiment, students are provided with a survey consisting of 12 questions. Questions are designed in two formats: multiple-choice and short answers. multiple-choice questions indicate the quality of remote lab experienced by the students and Short Answer questions allow students to provide input on the changes that should be made in order to enhance the remote lab experience. Questions of this survey seek to evaluate three key functions of the remote access technology:

1) Laboratory Manual Usefulness
2) User Communication Quality
3) User-friendliness Interface

Figure 6 depicts the result of the user satisfaction based on the user experience. This result shows the average satisfaction of the users completing all experiments. This chart is the result of the survey submitted by students during the Spring and Fall semesters in 2013. According to this chart, almost 90% of the users are fully satisfied with the performance of the remote access framework and even prefer conducting the laboratory experiments remotely.

During the survey, students submitted several comments regarding their remote connection experience. Latency has been mentioned as one of the key issues in remote access connection, particularly, for students who have lower internet speed at home. Improving the latency between student input and output from the IPKVM was a key priority during the testing. The time between the keyboard and mouse input and movement on the video is called the "input latency" and is a main factor in the usability of the laboratory.

In order to mitigate the inefficiency, two remedial approaches were used. One approach was video compression where we examined different compression settings under client side of the remote access system. This approach facilitates the process of choosing the best video compression setting on the client side (i.e., remote student). It was found that when compression and color depth settings were allowed to be automatically determined by the client, the quality of experience is suboptimal.

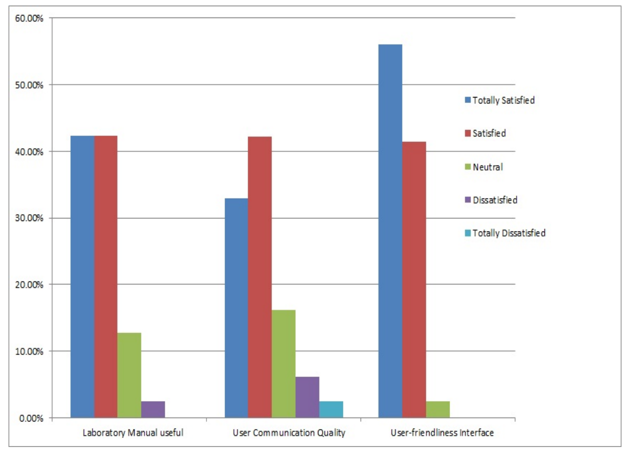

Figure 6. User Satisfaction Percentage

To further reduce the latency, a special feature of the IPKVM called "double mouse pointer" mode was enabled. This second remedial option makes the mouse pointer at the remote user terminal interface as the active pointer and therefore gives some sense of smoothness. The double mouse pointer mode required that the acceleration and sensitivity settings of the workstations were set to a value defined by the IPKVM. This was accomplished through altering the Xorg [16] configuration on the workstations. When enabled, two mouse pointers are visible in the IPKVM window. One is the local mouse pointer and the other is the remote pointer. The remote pointer always follows the local pointer and mouse clicks occur only when the remote pointer reaches the current location of the local pointer.

Finally, our remote access system and IPKVM support wireless connectivity as well. Since most of the students use Wi-Fi connections to reach the remote IPKVM, results in the chart proves acceptable quality of communication for wireless Internet. Procedural issues were another major source of confusion. It was found that students preferred to wait until the last possible moment to perform their labs. This culminated in a collision when multiple students tried to access the equipment concurrently. Thus, it became necessary to schedule time slots on a weekly basis during which students had uninterrupted usage hours to complete their experiments.

VI. CONCLUSION

Implementation of a remotely accessible networking course allows more students to have hands-on experience with the same type of equipment that is used in industry. Through this study, two network standards namely VLAN and IPKVM are utilized to design a framework which implements the remote access technology for different applications. Specifically, IPKVM is found to be the most effective method for providing remote access while meeting the security requirements intrinsic to most university networks. Furthermore, using VLANs is an efficient method for allowing the creation of various networking topologies in security, administrative and networking practices. Latency is found to be the single most important issue to be addressed when implementing remote access. Two methods are applied to reduce the effect of latency. The results from several survey submitted by students show that this framework has been successful in remotely conducting hands-on experiments.

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