INTRODUCTION

Hands-on laboratories are essential in computer network education. A good laboratory environment needs to be highly flexible and configurable to simulate a wide range of computer networks for experimentation. However, it is difficult for educational organizations to keep up with this complex and ever-changing area as computers and communication technologies keep on evolving.

Cloud-based virtual computing is receiving significant attention. It provides enormous and flexible computing power so that one system can satisfy different requirements with optimized computation and resources. This paper presents a cloud-based resource and service sharing platform for hands-on networking laboratory design, called V-Lab, which is a subdomain of the mobile cloud computing platform called MobiCloud (http://mobicloud.asu.edu) established...
at Arizona State University. MobiCloud utilizes XenServers and control devices to allow mobile users to create virtual computers and networks in the cloud to perform backend computations and proxy-based security features, enabling V-Lab to provide cloud resources to both desktop and mobile users. As this suggests, V-Lab does not place restrictions on platforms. The web-based GUI of V-Lab is developed using java applet, which has native cross platform support. Mobile users can access V-Lab through mobile web browser app and manage their resources, just as desktop users can do. Once the resources are created, mobile users can remote access to virtual computers through remote desktop clients on mobile devices.

V-Lab is built on top of Xen Virtualization (Xen Virtualization, 2012) and Virtual LAN (VLAN) (Wikipedia, 2012), which serves as a cost-effective, highly scalable and customizable Infrastructure-as-a-Service (IaaS) cloud platform, where students and instructors can create, configure, perform, and monitor laboratory resources via Web, SSH, VNC and RDP. V-Lab is established based on the following technologies:

- V-Lab uses Xen and VLAN to implement a mobile, cloud-based virtual resource sharing and configuring platform that provides laboratory computers using Xen Virtual computing and laboratory networks using VLANs. The virtual resources are dedicated to each student and isolated from other student’s resources, providing a secure and private laboratory environment throughout the curriculum.
- V-Lab uses ASP.NET, MSSQL and JavaScript to develop an interactive web 2.0 interface for V-Lab platform, where instructors and students can dynamically customize and configure laboratory virtual resources anytime throughout the semester. The web interface also helps students communicate with teammates, get support from Instructors, share and demonstrate laboratory works and results with other students.

The development of V-Lab includes an iteratively designed laboratory curriculum for computer and network security courses that leverage six educational factors: motivation, knowledge, creativity, collaboration, demonstration, and feedback. For each factor, we define a few educational tasks to be performed by students and instructors using V-Lab platform. The curriculum was also tested and satisfactory educational results.

This paper is arranged as follows: first, we provide a brief comparison between V-Lab and currently available computer network education solutions. Then we describe the design considerations and technical details of V-Lab. Afterwards, we present the laboratory curriculum and then provide the results of the preliminary V-Lab evaluation. Finally, conclusion and future work are presented in the last section.

**CURRENT HANDS-ON LABORATORIES**

In general, there are currently five types of hands-on laboratories among campuses. In this section, we compare V-Lab with existing laboratory solutions that are utilizing virtualization technologies at various extents. The comparison results are shown in Table 1.

*Physical Lab* is built with physical equipment such as routers, switches, hubs, PCs, etc. This type of laboratory can simulate real-world problems but it has drawbacks: (1) Physical networking systems are difficult to be reconfigured when laboratory requirements change, therefore it is only useful for classes with similar network system setup requirements; (2) Physical systems usually require technical supporting staffs; (3) Students need to schedule laboratory times to share one physical laboratory.

*Virtual Application Laboratory* provides free use of expensive software to campus students via Internet connection. The virtual computer laboratory systems used in My Apps system in Arizona State University (ASU My Apps, http://ets.fulton.asu.edu/), Geneseo
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