A Collaborative Virtual Computer Security Lab

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Abstract

The necessity of a lab course on computer security arises from the students' need to complement course work by hands-on experience. In order to meet the distance teaching demands of our institution, we designed an internet-based laboratory. We sketch the types of tasks the students are to perform, and our approach to check immediately whether students have completed a task. Yet, the typical tasks in labs only cover work done alone, while security engineering often comprises tasks involving several independent parties. This in turn calls for collaborative tasks, which we sketch. As students operate in larger groups, and the server hosting the lab machines can only run a finite number of them simultaneously, a reservation scheme is employed to guarantee fair access for all participants.

Keywords*: Education, remote laboratory, resource sharing, IT-security, virtualization, semi-automatic assessment*

1. Introduction

Computer security gains a growing importance in computer science and engineering curricula. Yet, courses on this subject have to be complemented by practical lab work in order to achieve full understanding of the subject matter. While this holds true for many branches of computer science, the value of training in computer security should not be underestimated: a subtle flaw in a firewall or a proxy server configuration can render useless all remaining efforts to secure a computer network!

For this reason we set out to define a set of tasks to be trained by computer science students in our computer science programme. As our institution is a distance teaching university, we specifically defined this lab course to be workable from a distance. Yet, as we focussed on network security, this was not really an issue, as most administrative tasks nowadays are not performed at a computer's console anyway, but via a remote shell or web-based via a browser. Yet, some of the tasks require collaboration among the student participants, which is challenging from a distance, yet still realistic: in a company beyond a certain size, collaborating administrators from different departments typically sit in different locations as well.

The main issues to be considered were the following. First, a student and his supervisor need feedback on when a task is correctly performed. As many tasks consist in installing and/or configuring tools to protect a part of a network, this has to be done via a test. A hint whether the task is completed should be generated automatically, in order to relieve students from the unproductive waiting time until a human supervisor has checked their work. The latter happens still, but when the hint already indicates that there is still a hole in the firewall configuration, there is no need for the student to wait, and for the supervisor to be bothered. We achieve this by carefully designed scripts, and log-file screening.

Second, as a consequence of the large number of students in the lab course, many machines have to be provided. As network security often deals with regulating the communication between two machines, each student is provided two machines, one being the one to be protected, one being the "external" one that implements an attacker. As most of the tools in the lab course, such as IP filters, intrusion detection systems and the like, change machine configurations, machines cannot be shared between students although the machines run the multi-user operating system Linux.

Third, the large number of machines not only has to be provided but also actively maintained. If a student, working with administrator rights, misconfigures some tool, he may well have destroyed the whole machine configuration, so that it is necessary to get the system back in a stable state. This is difficult from a distance, and sometimes impossible, as the only solution may be to install the operating system anew. Besides the effort to do this, this would prevent the last task in a sequence of tasks being dependent on the completion of the earlier tasks, which is unrealistic in a normal network setting. We achieve both tasks by employing virtual machines. While the use of virtual machines has been reported recently for a lab course on operating system administration [3], the goals there were different, and we are not aware of a security lab course employing virtualization.

Fourth, although we employ a powerful server to host the virtual machines, the large number of participants prevents the students from all being active simultaneously, as the server can only run a restricted number of virtual machines simultaneously without being annoyingly slow. This is not really a problem, because the students, that normally work part-time and study part-time, have quite differing preferences with respect to their study hours. Yet, there is the need to coordinate their working hours by a reservation system, so that, when a student spends his scarce time on the lab course, the server is in fact available to host his virtual machine. This reservation system is the first collaborative action in the lab. In a second part of the lab, students to work in teams, e.g. to realize a Virtual Private Network (VPN) between two machines that are independently managed. Therefore, the reservation system already must take into account the coupling of student actions. Also the students shall have the possibility to communicate with one another comfortably, being able to have a log of their actions or being able to show configuration files to one another. We implement these features by employing the web-based collaboration tool CURE [2].

The working interface to the student is a remote shell, as is usual for system administration tasks in Linux systems. Yet, the students also need an interface to see their performance chart, the tasks alongside with links to further documentation, and hints towards the solution, and so on. Here we provide a web-based interface, that is coupled to a database that contains the participant data and their performance data.

The remainder of this article is organized as follows. In Section 2 we sketch the architecture of the virtual network connecting the virtual machines of the students. In Section 3 we describe how we designed the tasks so that their completion can be efficiently checked. We also report on interface and collaboration issues. In Section 4 we conclude and give an outlook on future work.

2. Lab Network Design

Figure 1 depicts the design of the network for the virtual lab course. The students connect via the internet to the lab server. The server's physical IP address *.*.*.100 is only used for maintenance purposes, and accordingly protected. The virtual network's connection to the internet is via *.*.*.101. This virtual server serves as a firewall and as a router to the network itself via a private IP 192.168.100.1. The network address translation (NAT) is also performed in the virtual server. The virtual machines for the students are also in this network, they are depicted on the right. The server has a third virtual network interface (172.16.69.*) which only serves as a connection between physical server and virtual server, and hence will not play a role here. All virtual student machines have a second network interface towards a network 192.168.101.*, to connect them to the test server 192.168.101.1. This test server realizes a shared "external" machine, needed to test completion of some tasks.

There is a straightforward rationale behind this architecture: The physical server itself shall only be accessible for administrative purposes such as configuring the VMware server that provides the virtual machines and the virtual network. Hence, this server can only be connected from a particular external computer in possession of the administrator. From this fact arises the need that the connection between the virtual server and the internet, which is used by the students to log in, has to be realized by a virtual network interface. As the virtual server also shields the virtual network against outside attacks, the connection to the virtual network requires another virtual network interface. A third virtual network interface is needed to communicate between virtual server and physical server. As three virtual network interfaces is the maximum number provided by VMware, there is only one network interface connecting to the virtual network of student machines. Those machines are the ones to be protected. However, there must also be an "external" machine that is used in the course of the tests at the end of the tasks. This machine has to be put in a different subnet. As it cannot be connected to the virtual server, there arises the need to connect this machine with the student machines by a second virtual subnetwork.

3. Task Design, Interface and Collaboration

3.1. Task and Test Design

The lab course start with the simple task that the students must acquire a digital certificate of our university, install a VPN client and a secure shell tool at their home computer, and securely connect to the lab server. Further tasks then detail installation and configuration of a simple firewall (iptables), of intrusion detection systems (tripwire and snort), and of network address translation.

With the example of the firewall we explain our philosophy for checking completion of tasks. A typical requirement for a firewall is that some services (identified via ports) are not accessible from the outside, or are only accessible from particular external computers. After the student has configured the firewall, he starts a port scan from an external virtual machine. This port scan will generate log entries

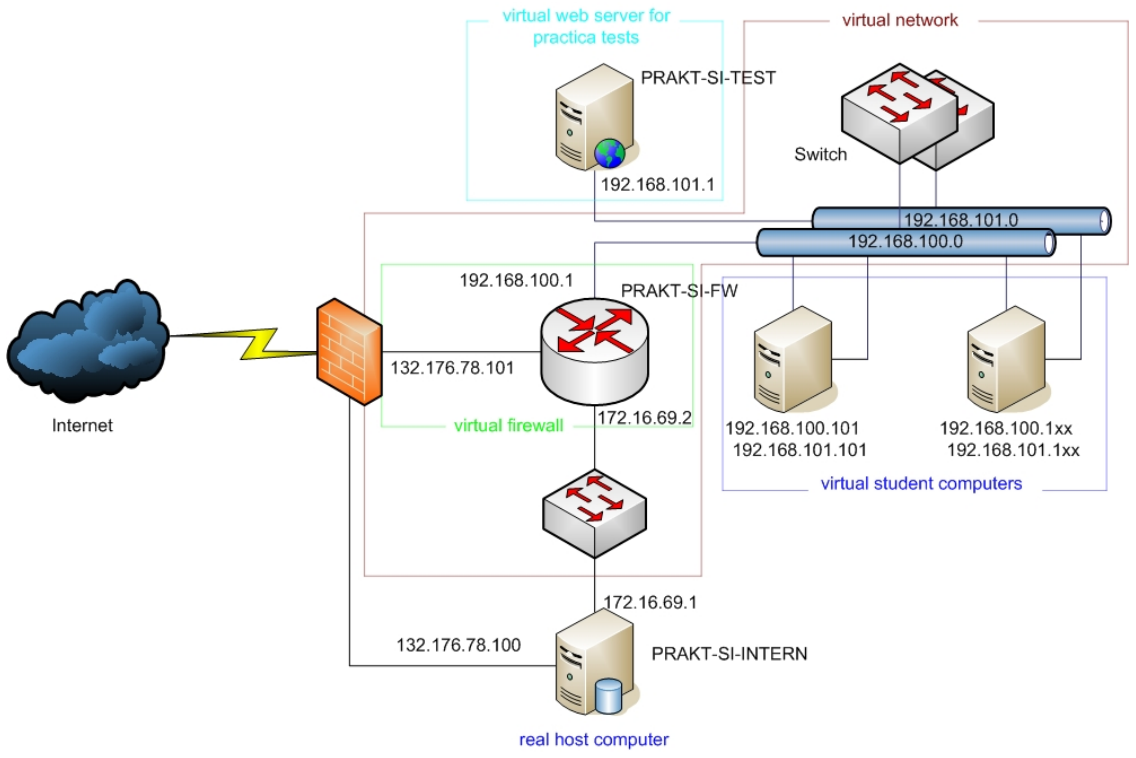


Figure 1. Design of Virtual Lab Network.

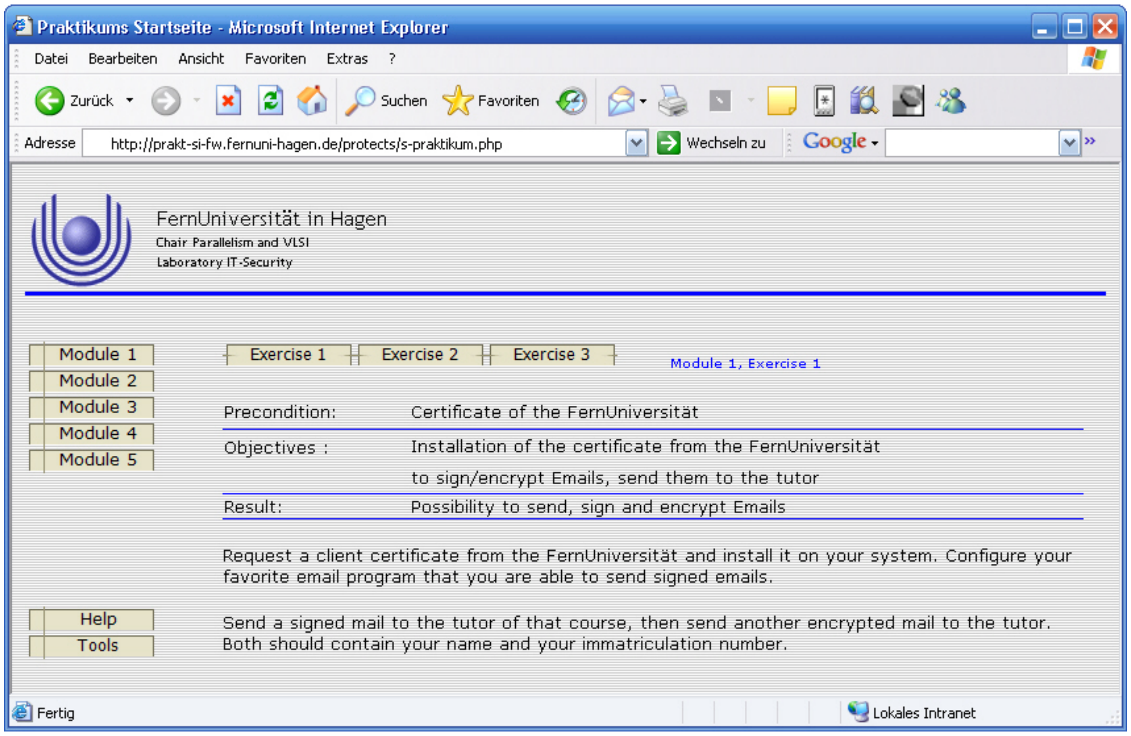
in the firewall log for all accesses that were denied. If the firewall is correctly configured, then this port scan will also generate log entries for the service just restricted. The student completes his task by starting a script. This script will search the firewall log for the appropriate entry. If it finds the entry, then the task is considered completed, otherwise not. The script sends its results to the server where the results are entered into a database. When the student now looks at his personal task performance web page, he sees whether the task is indeed completed.

A task is considered to be completed if the log file contains violations exactly for those actions that should be forbidden, i.e. it is also checked that there was not more restricted than demanded. While this seems a minor point, it is not to be underestimated in practice, because users are quite annoyed if after a firewall change, they are not able anymore to do their daily work. Also, a student may otherwise be able to complete tasks by simply forbidding everything. Obviously, the design of the tests influences the design of the tasks themselves. While the domains of the tasks are fixed beforehand, the particular task has to be put in a way that allows to be tested efficiently. Fortunately enough, the security field seems to pose no difficulties in this respect.

3.2. Student Interface, Collaboration

The interface towards the student is web-based, see Figure 2. The students log into a web server that resides on the virtual lab server. There, they can access their personal performance chart together with the log excerpt, so that they get hints why they did not yet complete a task. Also, they can see all task formulations, together with links to tools and manuals, and with hints. In principle, a web-based secure shell frontend could have been integrated with those pages, so that students only would have to use a browser. However, as the secure shell tool is the standard tool for system administrators to work with, we thought it more realistic not to do this.

The students are supposed to use a second web-based interface, the CSCW tool CURE [2]. CURE provides the concept of rooms, where students can meet in groups, can post documents, comment on them, and perform similar tasks. Also the logs can be posted there to archive records of what has been done. CURE thus supports the collaborative tasks. A typical collaborative task is the installation of a communication channel between two systems that are administrated by different authorities, and thus with different policies. While both systems may have identical hardware and run the same operating system, the configuration still



Precondition:	Certificate of the FernUniversität
Objectives :	Installation of the certificate from the FernUniversität to sign/encrypt Emails, send them to the tutor
Result:	Possibility to send, sign and encrypt Emails

Request a client certificate from the FernUniversität and install it on your system. Configure your favorite email program that you are able to send signed emails.

Send a signed mail to the tutor of that course, then send another encrypted mail to the tutor. Both should contain your name and your immatriculation number.

Figure 2. Student interface.

tends to be slightly different. This often leads to the necessity to exchange log-files or configuration files. As those often contain quite sensitive data with regard to security, they should not be sent by email but put in a secure place where only the people concerned can have access.

Still, CURE has not been designed primarily with such an application in mind. Therefore we are keen to see students comments on the suitability, and proposals for improvement, in the coming semester.

The CURE rooms are entered with personalized keys, so that only the students of a group can enter a particular room. CURE has been extended to provide time-dependent keys to control access to a remote hardware lab. Hence, CURE can be used as a reservation scheme for the virtual server, to prevent overload. The maximum number of simultaneous reservations must be adapted to the server hardware in use and the typical load that current tasks provide.

4. Conclusions

Our virtual computer security lab has passed the first user tests and will be used in the coming semester for a lab course with about 50 students. Our current platform limits the number of concurrently working virtual machines to about 15 out of performance reasons. Therefore the reservation scheme is indeed necessary. Currently, there are two web-based systems in use: the CURE system is used for reservation and collaboration. The web-based interface for performance monitoring has been developed separately. The two systems are only connected by links. Here, a tighter integration (e.g. only one login) is intended.

The performance of servers providing virtual machines will be greatly accelerated in the very near future, as the leading processor manufacturers Intel and AMD both have announced hardware support for virtualization in their processors [5, 1]. This will allow to increase the number of concurrently running virtual machines on a given platform, thus enabling deployment in even larger courses. Some courses where lab excercises will be advantageous have enrolments of several hundreds, so that currently students have to use their own computers, which raises lots of questions because of differing operating systems and similar things.

More future work centers around the extended use of virtualization. For example, a compact disc containing a CD-bootable Linux version like Knoppix [4] and a ready-to-run virtual machine configuration could be provided to the students, so that they can use their own computers for part of the lab tasks, without the danger of changing their normal configurations. The ability to save a virtual machine state and couple it with a player to run it on another machine is now provided by VmWare [6]. The challenge here is to create a virtual network of these distributed virtual machines so that collaborative tasks are still conveniently possible, and to link students from their homes to the collaboration platform.

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