Approaches to the Design of Computer Networking Laboratories

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ABSTRACT The provisioning of computer networking laboratories is a necessary task for academic programs that teach computer networking related topics. The following paper provides an analysis of the characteristics and possible evolution of different types of laboratory designs traditionally used in educational institutions.

KEYWORDS: Laboratory, Networking, Design, Teaching

INDEX TERMS: Remote Access, Lab Design, Centralized Topology, Distributed Topology, Simulation, Virtualization

1. INTRODUCTION  
The importance of computer networking technologies makes the methods and facilities used in the delivery and discovery of knowledge related to them very relevant in the planning of curricular activities at any educational institution.

Computer networking laboratories are a necessary component for institutions/programs that teach computer networking related topics. An adequately designed laboratory design should allow for easy management and flexibility in the type of experiences that can be performed in it [3]. Having a forward looking mindset is essential in the planning of these facilities to ensure a lasting educational impact. Also relevant is the adequate planning of the experiences (experiments/assignments) that the students will conduct in the lab so that they approximate or replicate real world experiences is also relevant.

This work provides an analysis of the approaches to the design of computer networking laboratories. For this analysis, a review of the literature related to the implementation methods for these facilities as well as the technical experiences of one the authors have been used. The common types of laboratory designs will be analyzed; the effect on teaching methods for each design and the issue of remote access to a computer networking laboratory facility will also be addressed.

An analysis of relevant literature reveals that there are three major types of networking laboratory structures and by no means are they mutually exclusive nor is this an exhaustive list of laboratory types [1 – 12]. The main types are laboratories based on a physical, simulated or virtualized infrastructure.

Laboratories based on a physical infrastructure provide many advantages including, real interfaces, results and interactions that can mimic those found in real world environments. Among the challenges to setup these facilities are the allocation of physical space, their cost to build and maintain.

Simulation software can be used to teach networking topics. Popular software includes ns2 and OPNET. Simulation software allows one to build networks and instantiate network devices at will through the software’s graphical user interface. When configured properly, the software will simulate the network as if it were a real one. Some advantages of this type of setup include that there is no real network to possibly damage and therefore simulation provides a very safe environment for learning. The size of the simulated network depends on the computational power and time allocated to this effort. The problem with this type of design is that the results of the simulation are only as good as the code written into the software and therefore there is a risk of not getting realistic or accurate results from the simulations.

The third type of lab that can be devised is a virtual lab. It is important to understand that the term ‘virtual’ has recently taken on several different meanings. In some instances ‘virtual’ has come to mean remote access. Keep in mind there can also be ‘remote access’ to ‘virtual’ infrastructures. Remote access and distance learning will be discussed later. For our purposes, a virtual networking lab is one that uses virtualization software to create virtual images of the software and hardware components of a network. Figure 1 illustrates the different design approaches for computer network laboratories.
2. LITERATURE SURVEY

The following section will survey some of the literature already published about designing networking laboratories. Again, this is neither an exhaustive nor mutually exclusive list only an effort to provide some reasoning behind the different approaches to laboratory design.

McCune et al. [1] have proposed a reconfigurable physical network laboratory for teaching many different types of classes. Their design also makes use of virtualization technology. The use of virtualization allows for the administrators to easily create virtual OS images that can be easily transferred to the student’s computers. According to the authors a 75% reduction in time required to set up the lab can be achieved by using virtualization techniques to arrange 18 student computers for the many types of lab experiences supported. This is an example of how the use of virtualization and physical infrastructure are not mutually exclusive in lab development.

Vivar and Magna [17] propose creating a physical networking lab that connects to a central hub that is then connected to the internet allowing for a physical lab accessible to anyone remotely.

There are many references featuring the virtual lab as the most effective method of teaching students about networking. Gerdes and Tilley [7] propose using a virtual laboratory to solve three issues

i. High upfront costs
ii. Space constraints
iii. Cost of maintenance and monitoring

They note that cost savings for hardware are somewhat mitigated by the necessity for high performance machines capable of running multiple virtual machines.

Baumgartner et al. [2] describe the use of virtual routers to emulate physical networks. Virtual routers are individual software processes that process data packets just as a real router would. They are not subject to the problems of simulations nor are they subject to the high cost involved with using physical networking hardware. Although there are many advantages to using virtual routers one must be careful when running multiple virtual routers on one machine as the host OS will allocate resources according to its own instructions and therefore may interfere with the real time processing of packets [2].

Perez-Hardy [12] proposes the use of network simulation tools in an effort to solve the following problems

i. Cost of monitoring equipment
ii. Maintaining hardware and software
iii. Scalability
iv. Remote access

She chose to use OPNET because it is object oriented and provides tools to create a simulated network that mirrors all of the characteristics of a real network. She also finds great value in OPNET’s advanced performance and analysis capabilities allowing students to see exactly what they are doing well and what they are not.

Remote access capabilities to laboratories is a topic of growing interest in the design of computer networking lab facilities. The objective of remote access is to provide students with the ability to control and configure physical, simulated or virtualized hardware and software from a location other than that where the hardware and software are physically hosted. Sloan [15] notes that although there are many benefits to remote access the designer needs to take into account three important challenges.

i. Security
ii. Manageability
iii. Authenticity

Security refers to the capability of controlling access to the lab’s resources. Manageability is the attribute of making the lab easy to change, modify and repair. Authenticity is the ability to provide thought provoking activities that promote competent learning of important concepts [15].

Hua and Ganz [9] realized an important aspect of remote access is the ability of students to collaborate, cooperate and communicate among themselves and with the instructors in real time. It is important however to note, as Gravier et al. [8] do, that collaboration and cooperation are two very different things. “In cooperation, partners split the work, solve sub-tasks individually and then assemble the partial results into the final output. In collaboration, partners do the work together.” [4].
3. CHOOSING A DESIGN
The following analysis is not designed to reach a conclusion as to which type of design is the best but, merely to compare and contrast the different types of designs so others may use this to help them make decisions about which design to implement based on academic and budget objectives.

The question of which type of laboratory design approach to use is not an easy one as compromises in the development of a lab facility are going to be necessary. Compromises are established on the basis of availability of physical space and of funds for the laboratory, costs of software licenses and previously installed infrastructure to just mention a few.

Physical labs, as discussed above, are developed using physical hardware and associated software. There are two topologies for a physical lab setup: centralized and distributed. A centralized topology, as illustrated in Figure 2 refers to having only one set of network hardware devices centrally located for easy access and maintenance. This however limits the availability to students as only one group can work at a time. 

A distributed (decentralized) topology, as illustrated in Figure 3 is composed of several workbenches each with its own network devices allowing more than one group to work at a time and even interconnect workbenches. This approach however is more expensive and its management requires more planning [3].

![Figure 2. Centralized topology](image1)

![Figure 3. Distributed topology](image2)

The most important advantage to using a physical infrastructure is that it provides true hands-on experience that is most similar to the environment students will be working on when they leave school. Although some might consider that interactions with physical hardware are of limited value as most equipment configuration is done through a software interface [7], it is the task of the instructor to design laboratory experiences that will go beyond having the student blindly use the guides provided by a software interface and instead promote critical thinking and hands-on work. The greatest disadvantages to setting up a physical lab are space, cost and power. Robust physical labs will often fill entire classrooms and cost upwards of $100,000 to cover hardware and software for a lab capable of providing capabilities to serve 20 students [7].

Simulation software like OPNET and ns2 are designed to simulate real networks within their graphical user interface. This allows students to create networks of arbitrary size and test them without any of the physical hardware typically associated with networks. All one needs is a personal computer capable of running the software. One of the most conspicuous problems with simulation is the assumed accuracy of the software. If the software is not developed correctly the network will not work properly and students may not get accurate results. Without constant updates simulation software may not provide for capabilities that follow the latest technology changes but updating simulation software is generally easier (and more economical) than updating or upgrading real networking devices.

The simulation approach is the most dissimilar to real world hands-on work [14]. However, applications like Cisco’s Packet Tracer can provide very realistic device emulation features but they are vendor-centric and may have restrictions related to licensing and emulation of advanced device features.

Virtualized laboratories take some aspects of physical hardware and simulation based labs. Virtualization allows multiple physical devices and software instances to be instantiated within a single physical machine. Elements such as hosts with different operating systems, router devices and the connections between them can be virtualized. An example of a virtual network might look something like Figure 4.

The use of virtualization for laboratory implementation involves using limited amounts of physical systems (mainly computers) and creating virtual instances of operating systems and networking hardware including routers in them[2]. Virtual labs can be
seen as a compromise between a completely physical infrastructure design and a simulation based design. An appealing aspect of virtual labs is that one can increase the size of the lab by adding limited amounts of new physical hardware and instantiating in them new network hosts/devices.

![Diagram of virtualized topology]

A popular decision in labs with virtualization is to setup student PC’s using virtual images of the proper operating system setup. This allows the lab administrator to create one correct setup and easily transfer it to each student computer. There are several commercial software applications that will help to create and administer a virtual lab. The most popular is VMware’s suite of applications that are used for creating and managing virtual machines. For setting OS permissions and virtual image management Microsoft Application Virtualization (Softgrid) provides a good solution. In an effort to summarize some of the characteristics of the different lab designs approaches table 1 provides a comparison among them.

4. REMOTE ACCESS TO COMPUTER NETWORKING LABS

In a world of increasing inter-connectedness, geographical boundaries are diminishing and lab designers need to take into account those who might need or want access to the lab from remote locations. Any of the three design approaches mentioned previously can be outfitted for remote access.

A physical lab can be connected to a web server that is accessible to anyone with an internet connection and can validate user credentials to allow access to equipment [17]. In general, providing remote access to physical devices in a lab infrastructure is a difficult undertaking that requires careful planning. Redundancy of connections to the lab and accessibility to its management/configuration platform need to be considered [15].

<table>
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<th>Table 1. Comparison of lab design approaches</th>
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<td><strong>Initial Costs</strong></td>
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<td>Simulation</td>
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<td>Physical (Centralized)</td>
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Remote access to simulation based labs can be provided through remote desktop technology or by having the student install the simulation software on a personal computer [14]. Virtual labs can also be accessed with the use of remote desktop technology [16] and if all of laboratory’s functionalities, including connectivity setup are implemented through virtualization software, the remote access would provide an almost equivalent experience to the remote user as that of the in-situ user.

5. TEACHING AND LAB DESIGN

The design of an instructional lab must be based on well grounded academic objectives which aim at successfully providing experiences to students that enhance their learning and comprehension.

Lawson and Stackpole [10] performed an experiment with their Introduction to Network Administration class at RIT. They had one group using remote access to a VMware server and another group using a physical lab with VMware workstations installed. Therefore one group was using a physical lab with virtual machine images installed and the other group used a remotely accessible virtual environment. The experiment found using a 95% confidence interval that the students’ success was not contingent upon the type of lab that they used.

Students mentioned problems with self motivation while using the completely virtual lab due to the added difficulty of using the virtualization software. Students using the virtual lab expressed their pleasure in not being constrained by lab access which is one thing their peers had complained about. Students using the in-class lab however had easier access to the instructors. Sicker et al. [14] set out to create a remotely accessible physical lab for a graduate program in Telecommunications. Their goal was to ‘reproduce’ not ‘emulate’ the lab experience. Students were assigned to either the formal in-class group or the remote group and the results of their experiences were analyzed.
Students in the in-class group scored better on all three direct assessment measures: Lab Execution, Exams and Practicum. The variations were: 5%, 5%, and 8% respectively. Qualitative surveys were administered to both groups; some obvious differences arose. Remote students found the teaching assistants more helpful but also reported feeling the pace of the class was too quick. Some students in the remote group also experienced technical difficulties with the remote interface. An interesting conclusion was that the remote lab provides a very good environment for repeating lab assignments even if the students had access to the physical lab the first time. Sicker et al. [14] note more studies need to be done on the effectiveness of remote lab access but the future is promising nonetheless.

From these studies we can see that learning outcomes can be similar if not equal when comparing remote access to local access. This issue needs further testing but is very interesting to the authors.

6. SUMMARY AND CONCLUSION

Laboratory experience is a necessary component in computer networking courses as a solid base of theory is of no use without the knowledge of how to put it into practice.

When building a new networking laboratory it is necessary to decide upon the type of approach to use: physical, virtual, simulated, or some combination of the three depending on which one better suits academic goals and needs. Among the issues to consider when deciding which type of lab to use include the following: cost, space, power, availability, remote access, course requirements, and commercial support. Cost will likely be the determining factor but sometimes a higher upfront cost will allow for greater accessibility, better devices and therefore greater use of the facility. If current trends are any sort of model for the future, remote access will be one of the most important aspects of any laboratory facility for the teaching of computer networking topics and their design, management and academic value should be explored further.

REFERENCES