Design and Implementation of the UULM Network Lab

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Abstract: We describe the foundation of a network laboratory for educational purposes in which it is possible to set up and manage different network scenarios. Students should be able to gather a better understanding of the concepts, technical challenges and design decisions behind the Internet. For this purpose we develop an educational concept for such a laboratory, identify necessary components and compose an encompassing technical architecture. Furthermore a modular concept for a management system to administrate the laboratory and the devices is introduced.

1 Introduction

About forty years after the research into a global, distributed network first began, knowledge of networking technologies has now become an essential part of any computer science education. The Internet with its enormous complexity and various facilities is however often hard to understand. Lectures aim to provide a theoretical background and try to further practical insights by offering accompanying assignments. However, these assignments often only cover a small part of the subject and usually do not provide hands-on experience with hardware which is actually used in existing working environments. Hence, students do not generally have the possibility to gain practical knowledge on how to build network scenarios with hardware from a productive environment.

We therefore aim to build the foundation for a network laboratory in which it is possible to set up and manage different network scenarios. The laboratory's purpose should be to serve as an educational environment. Students should be able to gather a better understanding of the concepts, technical challenges and design decisions behind the Internet. Over the period of one semester, students should set up core technologies within the laboratory, thus creating a macroscopic version of the Internet as part of a practical course.

2 Educational Concept

We aim for students to gain further insights into the technologies and inner workings of the Internet by gaining practical experiences and observing in further detail which tasks different operators have to fulfill. For this purpose students will have to complete assignments from the perspective of a variety of the typical roles which can be found in the Internet. For example, the assignments will require students to take on tasks which an ISP typically

performs: to administrate an enclosed *Autonomous System* (AS), which coordinates with other ASs and offers services to customers (e.g. server/web/mail hosting). On a more abstract level students will be required to coordinate the IP address space with other groups, a task for which the ICANN is responsible.

We found that consecutive Bottom-Top assignments best fulfill our educational requirements. In order to provide students with the freedom to choose for themselves on how to solve assignments we provide as little pre-configuration as possible. For example, we will not preconfigure routing or provide fixed cabling. Students will observe their own network set-up growing from a very basic set-up to a complex network scenario. During the course the groups will at first configure the devices within their group and later configure them to coordinate with those of other groups. We think this gives more insight into the concepts behind the Internet and rather represents its spirit—many independent organizations coordinating and communicating.

There are several projects at other universities which can be considered related to ours [LWMF10, MHL+10, wai]. From our understanding, there are several key differences to our concept. We aim to encourage students to gain hands-on experience with physical hardware, while abstaining from hardware emulations and instead offer physical access to the devices.

3 Technical Architecture

The laboratory consists of a variety of components. Racks are used to physically group different devices into logical units. From an educational and technical perspective, a set-up consisting of a number of equally equipped racks is most suitable, thereby allowing for various equal systems which can be flexibly interconnected. For example, each rack could represent an AS and thus be used to interconnect with the other racks. At least three racks are necessary to build interesting scenarios: for instance, failover problems only make sense with at least three different entities; if the direct route between two entities fails, the system should be able to adapt and use the third entity to balance the loss. Equipping the racks with identical equipment can be justified by an educational advantage; enabling three different groups to each work on a rack. Similarly to the racks, at least three routers and switches for each rack are essential for interesting scenarios such as failover or load balancing problems. Each rack will be equipped with exactly three routers and switches in order to keep the laboratory simple whilst still having a broad variety of options for scenarios.

The students need to have access to a server in order to configure a web server or use different network tools. We decided to equip each rack with one server with multiple Ethernet interfaces.

A separate management server is used to administrate the network laboratory. Serial connections connect the management server to each switch, router and server in the laboratory. Its purpose is to configure the laboratory and flexibly deploy configurations to the different devices. Student groups work on the management server with within their own virtual en-

vironment. The virtual machines restrain the groups' access to the devices that are assigned to a specific group.

We have additionally decided to set-up two separate VLANs in the laboratory. The *Student VLAN* is used by students to connect to different devices. The *Management VLAN* is used to deploy configurations for which the limited bandwidth of the serial lines is too small. This is for example necessary for the Virtual Machine images.

4 Management software

The network lab is set up in such a way that Out-of-Band management is supported: it is always possible to return to a working state. This is the single most highest priority of the management system, as otherwise a multitude of problems could occur. For this purpose, students working on devices do not have the necessary privilege levels to permanently change the device configuration. As a consequence, the system must administrate the necessary privilege levels for different assignments. Before an assignment starts, the privileges needed to complete the assignment have to be deployed to the devices.

Groups are able to save the state of their work at any time within a version control system. This provides a safe way of exploring the lab; by way of encouraging experimentation rather than constraining it. Thus we want to provide a safe way of being able to work with the lab. Flexibly deploying device configuration files also enables the students to enhance a specific network scenario without having to first build the entire scenario. For example, students may wish to enhance a company network e.g. with various security features. In this case, a company network scenario could be loaded and all devices configured accordingly.

We have implemented the management system within a first prototype. Our implementation hereby follows the Unix philosophy: Do one thing and do it right [Gan94, KP84]. We use different scripts for dedicated tasks, each fulfilling one function, remaining simple and small. A wrapper script is then used to compose the various scripts. Our initial set-up does not need any kind of database system. Instead, data is stored within flat ASCII files; a simple solution which has many additional advantages. It enables the use of tools from the Unix toolchest to rapidly build up the system logic. The project can easily be understood, maintained and enhanced using standard Unix tools (sed, grep, awk, etc.).

5 Conclusion

We have described the foundation of a network laboratory for educational purposes. Besides the educational concept, we have have described a technical architecture and a management system to flexibly handle assignments. The concept has been implemented as a first prototype with real hardware and, as a next step, will be evaluated with student groups.

Literatur

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[wai] The Wisconsin Advanced Internet Laboratory (WAIL) is part of the Computer Science Department at the University of Wisconsin - Madison. WAIL is home to the network research group led by Professor Paul Barford, Professor Suman Banerjee and Professor Cristian Estan.