

Open-Source Software Toolkit for Network Simulation and Modeling

Chengcheng Li

School of Information Technology

University of Cincinnati

Cincinnati, OH 45221

Chengcheng.li@uc.edu

Abstract

This paper summarizes a development of the best practices in network simulation and modeling using open source software tools. Though these tools, modules of lab exercises were developed to teach and conduct research in a wide range of networking topics, from basic LAN design and implementation, to WAN, switching, routing, IT services, security, and server configuration and deployment. The lab environment discussed in this paper was developed to teach a senior level IT networking course. Student evaluation indicates that the software-based networking lab is easy to set up and maintain. The lab modules facilitated students' understanding of the key concepts in network and system administration. More modules can be developed based on the software environment and rapidly deployed through a distributed lab approach to support a series of networking and cybersecurity courses.

Introduction

Along with the rapid evolution of network theories and concepts, innovative IT technologies emerge faster than ever before. The academic IT training curricula have to be updated frequently to keep up with the industry needs for preparing a qualified workforce. With a stringent and limited budget, the academia is getting harder to keep up with the industry's pace of updating and upgrading a lab infrastructure for teaching innovative network technologies. Computer network administration, design, and configuration are highly applied science disciplines in which hands-on skill practice is a critical component among student learning objectives. The industry needs a career ready workforce that is able to operate the enterprise-graded software applications and hardware appliances. However, constructing and maintaining a physical hands-on training lab for network and cybersecurity curricula can be expensive and time consuming. Although many software companies, such as VMware, Guidance Software, and Opnet, provide deep discounts or free licenses of their products for educational purposes and academic research, purchasing, housing, and maintaining a hardware network lab is commonly beyond the capacity of many institutions. Cisco Inc, the networking and communication industry market leader, started a Networking Academy program two decades ago, providing networking and security curricula to secondary and higher education. The program was well developed and created an international impact especially to vocational training institutions worldwide equivalent to the community colleges in the America. The 4-year university adoption rate of the Cisco program is relatively low because investing in a physical Cisco lab, required by Cisco academy program, will limit the universities to a proprietary and vendor-specific teaching environment; while universities usually favor using open-source software and teaching general

theories and concepts. Following Cisco’s successful education model, Juniper, another industry leader in networking and communication market, initiated its Academic Alliance program years ago. The Juniper program is more welcomed by the universities because it employs open source software and emphasizes research components in networking for faculty and upper level IT students. However, a multi-pod physical lab facility is required for adopting either Cisco or Juniper academic program.

There have been a collection of open source software applications and network simulation tools developed for teaching networking and security. Some of these tools, such as OMNeT++[1], NS2/NS3 (Network Simulator 2)[2] J-Sim[3] have been well documented and used by many network researchers. Opnet[4], a commercial but free for academic use network simulation and modeling tool has been widely adopted for networking research. A special scaled down academic edition of Opnet has been used in dozens universities for teaching networking lab. However, these simulation tools have a steep learning curve and require programming or scripting background. These simulation environments fit the needs of the CS majors to study theories but insufficient for the IT majors to learn applied hands-on skills.

This paper introduces a toolkit consisting of a set of open source network emulation and simulation software, used to create a network design and modeling environment with heterogeneous lab scenarios that simulate networking appliances and end-user systems of products from Cisco and other vendors. Network traffic can be conveniently collected for conducting teaching and research on packet level and protocol analysis. These tools include:

SOFTWARE	DESCRIPTION
DYNAMIPS	A network emulation program that virtualizes networking operating systems
VPC	A network simulation program that can instantiate up to 8 virtual PCs within the system memory. The virtual PCs only have basic networking capacity simulated through designated UPD ports but provide sufficient functionalities to test and troubleshoot network connectivity.
SUPPERPUTTY	A terminal emulator that provides commend-line based configuration windows for the virtual network appliances. It’s an enhanced version of PUTTY, the popular terminal emulator.
WIRESHARK	The most popular network software tool for protocol and packet analysis.
VIRTUALBOX	A free virtualization product that can virtualize multiple desktop or server operating systems into system memory, similar to VMware Workstation.
WINPACP	An API for capturing network traffic and simulating data communications between ports of the all the simulators and emulators.
GNS3	A software package that provides a graphic interface and a bundled installation of the above software tools except for Virtual Box which is copyrighted by of Oracle Corporation

Table 1. Open Source Software Tools for Constructing a Networking Simulation Lab

Class Setup

The discussed simulation lab environment was created in fall 2013 and used to teach a college senior level IT course in special topics of computer networking. The objectives of the course are designed to survey and give students sufficient hands-on experience on a wide range of networking topics. The class has three contact hours per week and was taught in a computer lab. Students were required to bring their laptops to the class so they could practice some lab exercises by following the instructor lab demonstrations. The reason that personal computer is required is because students in IT major already had hands-on lab in other networking classes. And most students already set up the virtualization network environment using Virtualbox and VMware workstation on their laptop. The university provides free license for Microsoft and VMware products to the students. A VMware vSphere lab is also created for the students. They can access the online lab via a standard web browser. However, the distributed lab on their laptops is preferred by the class because it is a critical skill and common practice for the field network engineers to set up their own toolkit. All the software tools used in this class are open-source software that can be installed on Windows, Linux distributions, and MacOS.

Sample Lab Content

A sample lab on Inter-vlan Routing is explained below to illustrate the setup and use of the simulation environment.

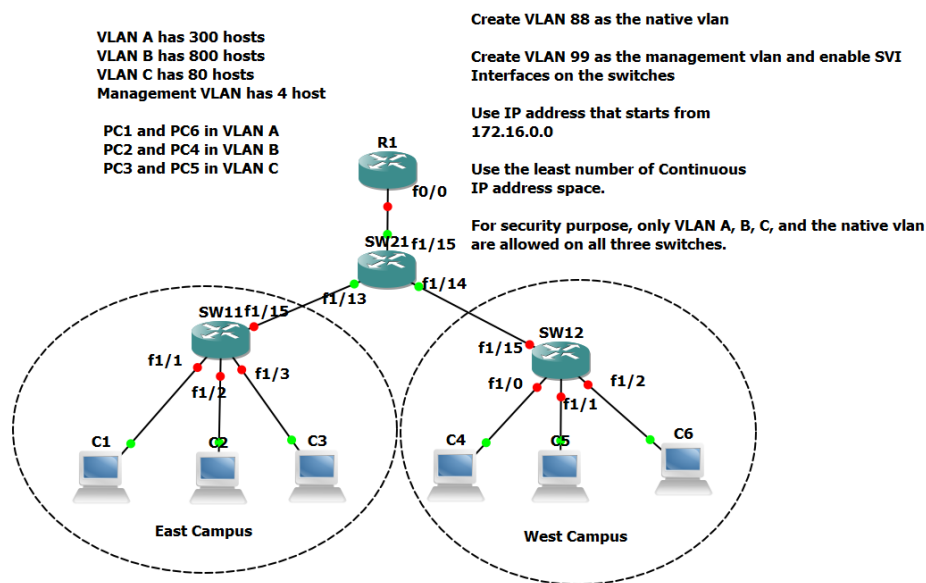


Diagram 1. Sample Inter-vlan Routing Lab Topology and Requirements

As shown in Diagram 1, the Inter-vlan Routing lab uses SW11 and SW12 as access layer switches connecting to two LAN segments, represented by 6 PCs, C1 to C6. SW21 is the distribution layer switch connecting to SW11 and SW12, and a router R1. You may notice that the switches in the diagram use an icon the same as a router. It is because SW11, SW12, and SW21 are actually routers with switching modules. They function as switches in this topology. There are three VLANs, VLAN A, B, and C. The 3 PCs in the two LAN segments belong to

different VLANs and they can't communicate with each other without R1 providing routing capacity, creating a "router-on-a-stick" network topology.

Before the inter-vlan routing lab was introduced, concepts of network infrastructure design and subnetting were reviewed. Students were required to create efficient IP schemes for the three VLANs. A VLAN database created on SW21 should be propagated to SW11 and SW12 through virtual trunking protocols (VTP). Students were asked to configure the correct VTP server and clients in this scenario for the VLAN database to be correctly populated. A VLAN99 was created for remote management of the switches through IP network instead of console connection. The native VLAN was moved from the default VLAN1 to VLAN88 for security reason. Next, switch ports should be mapped to the correct VLANs for communications within each VLAN. Trunking and encapsulation methods were configured on the link between SW21 and R1. Virtual subinterfaces are created on R1 to provide direct connection to each VLAN. Routing was not required to be configured because R1 has an active virtual interface in every VLAN. Finally, students would test the inter-vlan routing by using ping or traceroute commands on the virtual PCs. This lab summarizes a number of concepts in IP network design, switching, inter-vlan routing, and network configuration. This lab was taught during the third week of the semester before the students were introduced to routing and security concepts. This lab provides a foundation of knowing how to set up a lab environment and configure the virtual routers, virtual PCs, and other network appliances. Most students who were able to complete this hands-on lab without much instruction performed well in the rest of the class.

System Performance

The virtual lab environment was installed on students' personal laptops. MS Windows was used to demonstrate the lab activities during the class. Instructions of the installation and use of these open source software tools on Linux and MacOS were also provided. A cloud computing approach of using VMware vSphere is created on the university's "Sandbox" lab system. Students were able to use the VMware VMs through a standard web browser to access the "Sandbox", which is used as the backup lab.

These open source tools are not resource demanding. A typical PC with low-mid range CPU, 3GB memory, and 10GB hard drive is sufficient to run all the emulators and virtual PCs. The VirtualBox VMs may require more system memory and hard drive spaces based on the services and software installed on them.

Topics Covered

The special topic class covers a wide range of topics in computer networking. All the topics reviewed in the class are taught with the support of in-class lab demonstration and hands-on lab assignments designed by using the software tools. Larger topics are sometimes divided into subtopics. In-class lab demonstrations of these subtopics are helpful for students to grasp the theories and concepts and prepare them for the more comprehensive lab assignments. Table 2. Shows the class topics and subtopics that are mapped to lab activities.

Topics	In-class Demo	Hands-on Lab
TCP/IP Concepts		
IPv4 Addressing and Subnetting		X
IPv6 Addressing	X	
LAN Switching		
Virtual LAN and VLAN Database	X	
Virtual Trunking Protocol	X	
Inter-vlan Routing		X
Static Routing	X	X
Dynamic Routing		
Distance Vector Routing Protocols		X
Link State Routing Protocols		X
Border Gateway Protocol	X	X
Security		
Encryption	X	
Virtual Private Network		X
Access Control List	X	
Intrusion Detection Systems and Firewalls	X	
Network Services		
Dynamic Host Configuration Protocol Server	X	X
Network Time Protocol Server	X	
Hot Standby Router Protocol		X
Domain Name Server	X	
Network/Port Address Translation	X	X
Small Network Management Protocol Server	X	
Optional:		
Quality of Services	X	
Multicasting	X	

Table 2. Networking Concepts and Topics Covered by the Simulation Lab

Assessment

Student evaluation of the hands-on lab environment was collected at the end of the semester. The survey result shows that the majority of the students welcomed this hands-on approach and appreciated the convenience of lab setup on their laptops. They feel the lab exercises are challenging and the writing instructions alone are not sufficient for them to complete the exercises. But with the help of in-class demonstration and hands-on instruction, they are able to finish the exercises. The average hours the students spent on lab exercises are 6 hours per week which is the appropriate workload for a 3-credit course.

66.7% of students ranked the lab exercises as the number one teaching component that contributes to the effectiveness of the class, comparing to lectures as number two, project and presentation as number three, and quizzes and final exam as number four. Likert 5-option scales from “strongly disagree” to “strongly agree” were used to survey student responses to the

simulation lab. 21 of the 23 students in the networking class completed the survey. And a summary of the questions are displayed in Table 3.

Questions Regarding the Lab Environment	Combined Percentage of “Agree” and “Strongly Agree”
Q6. The lab simulation environment is an excellent tool for studying networking and system administration	85.7%
Q7. The labs are easy to setup on the simulation environment	61.9%
Q8. The written lab requirements alone are clear and sufficient for me to complete the lab.	33.3%
Q9. The lab exercises are challenging.	100%
Q10. The performance of the simulation lab environment is stable and meets my learning needs.	85.7%

Table 3. Summary of Student Survey on the Simulation Lab

Conclusion

This paper reviews a set of open source software tools used in a computer networking class for providing students hands-on experience on enterprise-grade network appliances. The successful setup of this set of emulators, simulators, and protocol analyzers replaces the needs of a physical lab that is expensive and difficult to maintain. A distributed lab approach allows students to perform lab exercises any time on their personal laptop during and after classes. A full set of lab demonstration and hands-on lab exercises that cover a wide range of networking topics are developed, documented, and ready for dissemination to other institutions that are offering similar IT curricula.

Acknowledgement

This research is based upon work supported by the National Science Foundation Grant No. 0837722.

Bibliography

- [1] Jun-Li Kuo; Chen-Hua Shih; Yaw-Chung Chen, "Performance analysis of real-time streaming under TCP and UDP in VANET via OMNET," *2013 13th International Conference on ITS Telecommunications (ITST)*, pp.116-121, 5-7 Nov. 2013
- [2] Rahimi, M.J.; Parveen, S.; Morshed, M.; Khan, M.R.; Sarker, P., "Development of the smart QoS monitors to enhance the performance of the NS2 Network Simulator," *2010 13th International Conference on Computer and Information Technology (ICCIT)*, pp.137-141, 23-25 Dec. 2010
- [3] Neves, P.A.C.S.; Veiga, I.; Rodrigues, J.J.P.C., "G-JSIM — a GUI tool for Wireless Sensor Networks simulations under J-SIM," *IEEE International Symposium on Consumer Electronics (ISCE 2008)*, pp.1-4, 14-16 April 2008
- [4] Jia Hao; Jiechang Wu; Chaoyou Guo, "Modeling and simulation of CAN network based on OPNET," *2011 IEEE 3rd International Conference on Communication Software and Networks (ICCSN)*, pp.577-581, 27-29 May 2011