

Simulation tool for active learning of introductory computer network subjects

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Abstract— Simulation software helps a learner of networking subject to have an active learning experience. There are many simulator tools available either freely or off the shelf. Hence, simulation tools need to be carefully chosen to maximize the benefit to the learners. In order to choose simulation tools, comparison is made from a number of simulation tools that are easily available for the public. The comparison made to the tools produce a recommendation of which tool is to be chosen in different study environments.

Keywords- computer networks, computer aided instruction, computer science education, electronic learning, network topology, hardware virtualization, next generation networking

I. INTRODUCTION

This paper focuses on tools that assist undergraduate students to learn introductory computer network subject, particularly software tools that act as network device simulator or emulator. As a technical subject, the computer network curriculum requires abstract understanding of concepts as well as skill-building practice. Traditional lectures alone are not sufficient to fulfill this requirement. Hence students need a tool that can help them to both understand that subject and carry out practical exercises.

II. NETWORK STUDY TOOLS

Network Emulators and Network Simulators

To enable learning of networking subjects, dedicated labs [1-3] with real hardware is compulsory to enable real life practice. However, it cannot be the only approach for learning the practical side of network because a complete lab requires high cost of acquisition, upgrade and maintenance [4]. The real devices, being expensive, can only be bought in a limited quantity, thus need to be shared by many students. As the devices must be kept in the lab, they are not accessible to all students all the time [5]. Using only real devices also limits the range of network conditions for students to experiment with [6]. Real devices also require hardware setup, thus taking more of the students' learning time [7].

Hence a number of other options are investigated in order to suggest an additional tool that can help students learning introductory networking subjects at undergraduate level. The options include network emulators, grid computing network

emulators, complex and simple network simulators, and finally networking device simulators and emulators.

The first option investigated is the network emulators like Nist Net [8], Dummynet [9] and Empower [10]. Network emulators are usually hardware devices that reproduce the behavior of a real network such as specific Internet topologies [11], wireless networks [12], [10] and satellite links [13], [14] without actually building the testbed. Although network emulation is useful for learning and research of computer networks, its deployment is as difficult as the deployment of a real testbed [6].

In addition, there are large scale grid computing-oriented network emulators such as Emulab, Planetlab, Open Network Lab (ONL) [15-19] and IREEL [6]. They are connected infrastructure consisting of real devices configured for network experiments. These grid-computing emulators are more suitable for research environment rather than teaching-learning environment because they need expertise to be built and maintained. These solutions also need real networking devices connected to the grid [6].

In the absence of real devices, full-featured event-driven simulators software like opnet, ns2, ns3, glomosim and OMNeT++ [20-24] may be used. They are developed to help the user to study the theoretical aspect of the network behavior, as done in many network related researches. However, these simulators are not recommended as a tool for teaching introductory networking subjects because they require the users (students) to put time to learn the modeling language and model abstraction. As this is outside the scope of most introductory networking courses, these simulators also do not introduce network device configuration and troubleshooting which is an essential part of introductory networking course [5-7].

On the other hand, less complex network simulators, such as cnet and the scalable simulation framework (SSF) [25], [26] lack some part of the networking stack and cannot be used together with standard network monitoring and debugging applications like tcpdump, tcpstat, Wireshark and snmp/mrtg [5].

The next subtopic will look at networking devices simulators and emulators and why these two types of solutions are better than the ones discussed above.

Simulators and Emulators as Network Learning Tools

A simulator is software tool that pretends to be another software application or hardware device by mimicking its functionalities. When a user enters a command, the simulator pretends that the command is being executed without carrying out the actual processing. The operations that a simulator can mimic are subjected to the constraints defined in the simulation software environment [4], [7]. Examples of network devices simulators are Cisco Packet Tracer, Boson Netsim and Networksims [27-29].

An emulator, on the other hand, mimics the full functions of a hardware device. A command entered by a user in an emulator will be actually processed. An emulator offers all functionalities of its emulated device [4], [7]. Examples of emulator programs are VMware and GNS3 [30], [31].

Unlike the network simulators and emulators introduced in the previous topic, the simulators and emulators used as a learning tool for introductory networking subjects simulate and emulate networking devices, not the network protocols behavior. Hence students can use them as practice tools to configure and troubleshoot network devices like routers and switch.

III. METHODOLOGY

This study begins with a web search of information related to the use of simulators/emulators in education. Recommendations are collected from forums of networking subject students and educators as well as users' forums of open source simulators/emulators. Next, literature review is done to collect credible sources for the study. The recommended tools are then evaluated through a study of their documentation and actual tests on a network configuration. Results are collected, documented, discussed and final recommendation is made based on the discussion of the result.

IV. RESULT

Table 1 summarizes five simulators and emulators that are used in learning and teaching of introductory networking subjects at undergraduate level universities. These tools are chosen from many others that are recommended in various network learning communities. Other tools that are not chosen are those that cannot run on Windows operating systems, or not suitable for introductory networking courses. As more universities now adopt Cisco-based curriculum, namely the Cisco Certified Network Associate (CCNA) certification for introductory networking subjects, the simulators and emulators chosen to be included in this study are those that can be used for CCNA certification study and those related with it.

Table 2 discusses the advantages and disadvantages of all the five tools chosen.

V. DISCUSSION AND RECOMMENDATION

Table 1 and Table 2 depicted the five chosen tools with advantages and disadvantages discussed. In order to recommend the best among the five, some important factors

are considered. Table 3 lists the factors and recommends the tools that are suitable to fulfill the criteria.

All the five tools discussed fulfill the first two criteria that is suitable to be used by students to study independently (possibly at home without the real devices) and suitable as a learning tool for an introductory networking subject that utilizes the Cisco curriculum, namely the CCNA (Cisco Certified Network Associate) certification.

In terms of study support for certification however, GNS3 does not directly provide it. What is meant by certification study support here are certification exam-oriented network device configuration exercises that come with the software. Tools other than GNS3 come with scenarios where students can attempt to solve and students' mark are calculated based on the accuracy of the students' configuration.

Among the tools discussed here, Packet Tracer is the only simulator/emulator that allows the instructors to create custom exercises in which the students' answer will be automatically calculated by the software. This can be utilized using the *Activity Wizard* function. In addition, Packet Tracer allows multiple users to collaborate using different computers on one network scenario through its own Packet Tracer Messaging Protocol (PMTP) [27],[32-35].

Due to the collaboration capacity of Cisco Packet Tracer, it can be used for the purpose of research and projects as done by [36]. However, the extent of project supported by Cisco Packet Tracer is limited compared to GNS3. GNS3 has more capacity to be used in a research and project, being an emulator that can emulate many networking devices and computers as long as the operating system images are provided by the users.

RECOMMENDED SIMULATORS/EMULATORS

Product Name	Operating system environment	License	User Learning Level	Availability to public
Cisco Packet Tracer	Windows, Linux	Proprietary, free for all Cisco's Network Academy students	Introductory	Free for all Cisco's Network Academy members only from cisco.netacad.net
GNS3	Windows, Linux, Mac	Open source	Introductory to high	Free from www.gns3.net
Boson NetSim	Windows	Proprietary	Introductory to medium	Free limited demo version from www.boson.com . Full version available with a cost.
MIMIC Virtual Lab CCNA	Windows, Linux	Proprietary	Introductory	4-days rent or purchase from www.gambitcomm.com
RouterSim Net Visualizer	Windows	Proprietary	Introductory	Free limited demo version from www.routersim.com . Full version available with a

				cost.
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ADVANTAGES AND DISADVANTAGES OF RECOMMENDED SIMULATORS/EMULATORS

Product Name	Advantages	Disadvantages
Cisco Packet Tracer	<ul style="list-style-type: none"> - Free for Cisco Networking Academy (CNA) members - Can run on Windows and Linux - Standalone - does not need other program to run - Simulation mode that allows study of network behaviors - Can be used collaboratively between multiple users and computers (students) - Include functions to assist instructors to develop exercises and marking - Developed based on research on CNA's needs for a simulation tool tailored for Cisco's introductory level certification study [37] 	<ul style="list-style-type: none"> - Not available for non CNA members - Limited range of devices and commands supported – not enough for beyond introductory level studies
GNS3	<ul style="list-style-type: none"> - Free and open source - Support full features of the devices and operating systems emulated - Able to interact with real network - Emulates a big range of devices and computer operating systems, hence useful for all levels of study and related research - Support VirtualBox (a free virtual machine software) integration - Has been enhanced specifically for use in undergraduate introductory networking course in [7] 	<ul style="list-style-type: none"> - Users must supply valid operating system files of all the emulated devices - Need other software installed like Dynamips, Qemu, Putty and Winpcap.
Boson NetSim	<ul style="list-style-type: none"> - Simulates a bigger range of devices and functions compared to Cisco Packet Tracer – can be used for study beyond introductory level - Include exercises with marking function to help independent study 	<ul style="list-style-type: none"> - Needs purchase - Runs on Windows only - Simulates Cisco devices only
MIMIC Virtual Lab CCNA	<ul style="list-style-type: none"> - Runs on Windows and Linux - Include exercises to help independent study 	<ul style="list-style-type: none"> - Needs purchase - Limited range of devices and commands

		supported – not enough for beyond introductory level studies
RouterSim Net Visualizer	- Include exercises to help independent study	<ul style="list-style-type: none"> - Needs purchase - Runs on Windows only - Limited range of devices and commands supported – not enough for beyond introductory level studies

Furthermore, with the ability to emulate high end networking devices with all their functions, GNS3 can be used to learn advanced networking subjects as well. As for Boson NetSim, it also provides exercises for curriculum beyond the introductory level CCNA that is Cisco Certified Network Professional (CCNP).

In environments where both Windows and Linux operating systems are used, Cisco Packet Tracer, GNS3 and MIMIC Virtual Lab CCNA can be used compared to the others which can operate on one operating system only.

Finally, in terms of licensing, only GNS3 is totally free and open source for users. As for Cisco Packet Tracer, it is free for students and instructors of Cisco Networking Academy, downloadable through the members' section of CAN website.

Due to all the factors discussed above, the simulator/emulator tools recommended for introductory networking courses are GNS3 and Cisco Packet Tracer for an institution that adopts Cisco Networking Academy curriculum. If the institution does not adopt Cisco curriculum, GNS3 is more than enough due to its capability to fulfill many important criteria above.

SIMULATORS/EMULATORS FULFILMENT OF LEARNING/TEACHING CRITERIA

	Cisco Packet Tracer	GNS3	Boson NetSim	MIMIC Virtual Lab CCNA	RouterSim Net Visualizer
Independent study	√	√	√	√	√
Cisco Networking Academy	√	√	√	√	√
Certification study support	√		√	√	√
Teaching support	√				
Users collaboration	√				
Research and project	√	√			
Learning beyond basic		√	√		
Windows and Linux	√	√		√	
Free	√ (CNA)	√			

VI. CONCLUSION

This paper discusses available tools that can be used to help introductory level networking subject students at undergraduate level. Each tool is categorized, and each category is evaluated against its suitability to be used in the context aforementioned. Networking device simulators and emulators are chosen as the suitable category of tools that can be used for introductory networking subjects.

Then, each tool in the category is evaluated based on its advantages and disadvantages for different requirement of learning institutions. Finally, a recommendation is made based on how some tool can fulfill the learning/teaching criteria better than the other tools.

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