Computer Networks Virtualization with GNS3

Evaluating a solution to optimize resources and achieve a distance learning

Pablo Gil, *Member IEEE*, Gabriel J. Garcia, Angel Delgado, Rosa M. Medina, Antonio Calderon, Patricia Marti
Computer Science Research Institute
University of Alicante
San Vicente del Raspeig (Alicante), Spain
{pablo.gil, gjgg, angel.delgado}@ua.es, {rmmg11, ach11, pmg57}@alu.ua.es

***Abstract*—Designing educational resources allow students to modify their learning process. In particular, on-line and downloadable educational resources have been successfully used in engineering education the last years [1]. Usually, these resources are free and accessible from web. In addition, they are designed and developed by lecturers and used by their students. But, they are rarely developed by students in order to be used by other students. In this work-in-progress, lecturers and students are working together to implement educational resources, which can be used by students to improve the learning process of computer networks subject in engineering studies. In particular, network topologies to model LAN (Local Area Network) and MAN (Metropolitan Area Network) are virtualized in order to simulate the behavior of the links and nodes when they are interconnected with different physical and logical design.**

Keywords—virtualization; computer network; simulation; GNS3; distance learning

I. INTRODUCTION

Traditional teaching methodology of a subject like Computer Networks has consisted of a face to face proposal [1]. In order to achieve the practical skills, students develop hands-on experiments in a laboratory in the university. They use a real computer network based on TCP/IP architecture where some computers with different operative systems are connected with physical network devices such as routers, switches, hubs, bridges, etc. Thus, the lecturers show the network behavior analyzing the packets traffic. Sometimes the students use several free applications for simulating the behavior of computer networks and TCP/IP routing. Generally, these on-line simulators (J-SIM [2], NS [3], Partov [4].) are based on programming languages and they usually are not intuitive and easy to be used by any student. For this reason, initially the lecturers implemented a new simulator called KivaNS [5]. And subsequently, they created interactive and portable Java applets [6] from KivaNS using EJS (Easy Java Simulations) [7]. These applets (KivaNS+EJS) are easy to be used and do not require to be programmed in order to simulate how protocols of the TCP/IP architecture work. But, the applets have a very limited re-configurability and the kind of network topology is limited by programming. Moreover, the traffic generated by these virtual networks is not real and the quality of information is also depending on the low-level programming. Consequently, we require an open source software that allows us to simulate how complex networks work from the virtualization of real network devices without dedicating specific hardware such as router, switches, hubs, etc. and where the students may analyze traffic as if it was being generated in a real network. GNS3 (Graphical Network Simulation) [8] is a tool that can help us to achieve these requirements replicating the configuration of interfaces and routers of our real computer network installed in a physical laboratory in our University. Therefore, in this work-in-progress, some activities based on the virtualization of a computer network are proposed. The activities are based on the existing network topology implemented on a laboratory of our University. Thus, our real devices are virtualized using the free library GNS3. The computer network virtualization provides to students some advantages such as: a) the student can analyze the real traffic without using real physical devices. The configuration and connectivity problems are reduced or eliminated. b) They can work from other places (home, job, library, etc.) outside the classroom/laboratory. The distance learning can be performed. c) The routing techniques can be changed by the students. They do not require special user authorization to avoid machine damages or changes on the configurations. In the real laboratory, some changes are not allowed because multiple users interact on the same devices and the changes can affect all users.

The new virtual computer networks topologies have been evaluated in a subject of communication and industrial networks of the Automatics and Robotics Master of the University of Alicante. The lecturers proposed a hands-on session over the real laboratory that can be developed already with the virtual environment using GNS3. A survey to the students evaluates the proposal, and the students' marks demonstrate if the new on-line tool is better for the improvement of the learning process of this subject.

II. VIRTUALIZED COMPUTER NETWORK SCHEME

The computer network topology virtualized is similar to the physical laboratory. The virtual network is shown in Figure 1. It was implemented according to TCP/IP architecture. Only two network links have changed their implementation respect to real laboratory. The Token Ring was substituted by Ethernet and the Wireless Access Points were eliminated because they cannot be implemented in GNS3

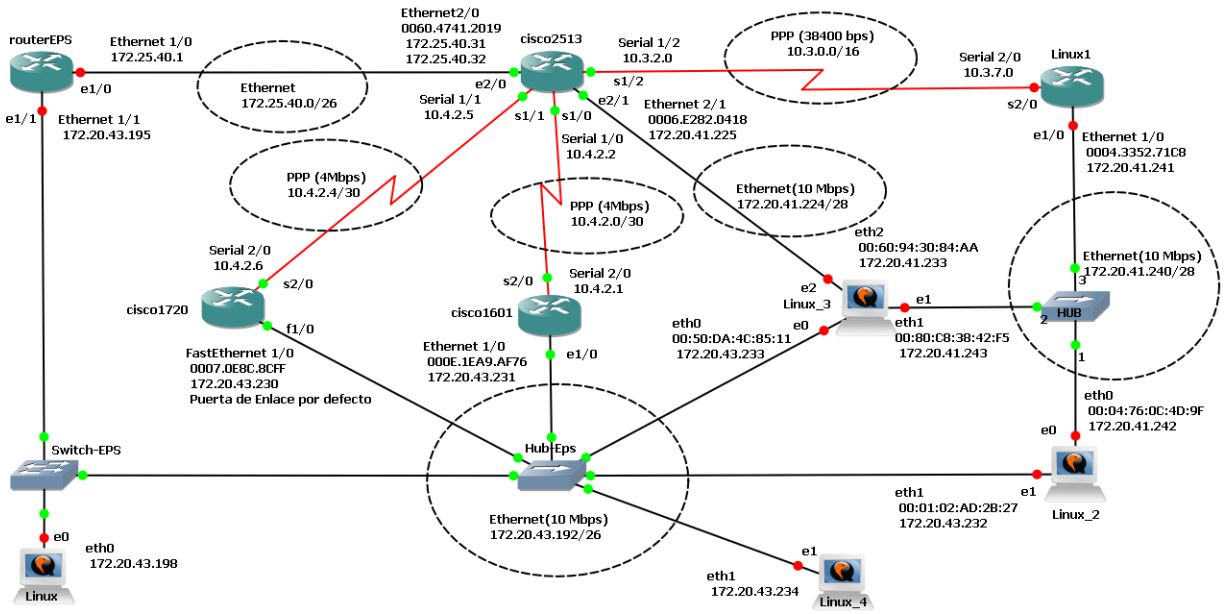

Fig. 1. Virtualized Network Computer Topology with GNS3

with the current version. The proposed complex topology was designed for learning how networks devices work (switches, HUBs and routers) and how several user operative systems can be configured to work in a computer network such as Linux or IOS (Operative System of CISCO routers). 'Idlepc' values for the IOS were used to reduce CPU usage of the real PC in which the virtual network is executed. 'Idlepc' values active or sleep the IOS nodes in GNS3, according the traffic and if they are used or not.

On the one hand, the virtual network is composed of three PPP and five Ethernet links connecting user devices emulated with two different platforms: VirtualBox [9] and Qemu [10]. A Debian Linux is running over VirtualBox to emulate the PC behavior in the physical laboratory. It uses GNOME environment to supply commands and network tools to the student. It is labeled as Linux node in Figure 1. Tiny Core Linux over Quemu is used to emulate the behavior of network servers (httpd, ftpd, telnetd, execd, sshd, etc.) and routing via software. They are labelled as Linux1-4 nodes in the Figure 1. Tiny Core is a super small operating system to spend on few hardware resources of the physical machine where it is running. An advantage of this virtual laboratory over the real physical laboratory is that the student has access to all nodes as root. Therefore, they can execute commands from console or terminal window without limiting permissions.

On the other hand, five CISCO routers are emulated using Dynamips. It is widespread among people who study for CCNA (Cisco Certified Network Associate) and CCNP (Cisco Certified Network Professional) certification exams. Although CISCO routers are different models in the physical network (1601, 1720, 2513), all of them are emulated with the same platform in the virtual network. An IOS based on the 7100 model was defined. The image file necessary to load in the virtual environment is obtained from our own real device. This model was chosen because it includes some slots to configure different network adapters using different link protocols used in TCP/IP architecture. Furthermore, the network topologies implemented from GNS3 allow us to have another advantage over the real physical laboratory. GNS3 allow students to test different configurations changing the addressing and routing information, analyzing Internet data traffic anywhere in the topology or control the network security adapting the configurations of access lists in the routers. Wireshark [11] is a packet analyzer integrated in GNS3 used to capture, sniff and analyze data packets according to both used protocols and encapsulated information on virtual Ethernet or serial interfaces.

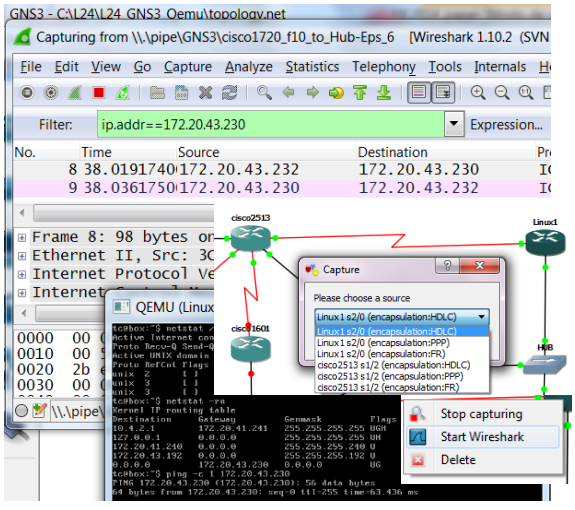

Fig. 2. Generating, capturing and analyzing traffic in our Topology

The course is structured as a set of sessions based on model presentation that explains the networking basic concepts and

follows generally recommended rules to server as an example to students. The course also briefly explains the basic commands to obtain information of devices, how the students can install and run GNS3 and how the students can capture and analyze packets from Wireshark. The course is studied by engineering graduates from different academic fields such as telecommunications, industrial, computers and electronic engineering. The work documents and the guide with experiments are published in Moodle [6]. Furthermore, the class can be followed face to face or remotely from video streaming. During the academic year 2013-14, 8 students took this subject and completed their activities and experiments. This subject is optional. The Master's degree is composed of 5 mandatory and 11 optative subjects, respectively. The 47% of students chose this subject as part of academic profile to achieve successfully the degree. The subject consists of three parts: a) basic concepts and overview of packets transmission over TCP/IP network architecture, b) industrial communication buses and c) industrial protocols for communication such as ModBus (over Ethernet and TCP/IP), Profibus/Profinet or Ethernet Industrial. The virtual computer network was only used for the first part of the subject. The objective was to make a pilot experience with few students who had little or no knowledge of computer networks.

III. ASSESMENT STUDY

The results of the 21 questions (Q1-Q21), related to the network topology and how it is executed over GNS3, are commented in this section. Students received an opinion questionnaire and completed it anonymously at the end of the course. In the questions Q1-Q3, our students were asked about if they knew other computer network simulators and the survey results demonstrated that only 33% knew other simulators but also 16.7% had only used those. From question Q4-Q9, referring to the overall results, our students opined about GNS3. Students consider very positive the capability to emulate the operating behavior of a real device and to configure its routing table and network interfaces, easily. Thus, 83.3% students think the functionality of GNS3 interface can be rated with scored of 3.2 over 5. In general, they had not problems with the installation and configuration process but if they had slight problems with the simulation process for understanding them. They highlight the GNS3 ability to capture packets in network links with different technology from different location (local or remote location in relation to the student node). Also, they indicated that the ability to emulate real routers and work with their commands is interesting. Notwithstanding, they missed the emulation of other operative systems of other router manufacturers and the simulation of other link technologies such as WiFi. In addition, they considered that GNS3 spends a lot of memory and CPU of machine where it is run in spite of the configuration of the 'Idle' parameter. Later, a study of the requirements hardware will be done.

Tables I and II, show the summary of responses to questions Q10-Q19. The students responded to the questions with a value of '1' to '5', with "5" indicating Strongly Agree. Most of users thought that the virtual network provides an acceptable sense of reality to emulate real experiments. Thus, the mean score was 3.5 over 5. In particular, table I shows that almost all of the students found our virtual laboratory based on GNS3 useful to learn topics in computer networks in general and to help understand topics about communications and TCP/IP in the context of the subject (3.5 and 4 were the scores over 5, respectively). Similar results were obtained when they were asked about virtual laboratory capability to give students the flexibility (time and location) for distance learning (3.7 over 4). But, in general only a score of 3 over 5 was achieved when they were asked about the similarity between real and virtual laboratory. Although, according to lecturer opinion, the virtual laboratory works almost 90% equal to the real laboratory, we think that emulator make the student loose the sense of reality.

TABLE I. SELECTED SURVEY QUESTIONS FROM OPINION RESULTS

Categories	**Student Opinion (from Q10 to Q13 and Q20, Q21)**					
	Strongly Disagree (%)	***Disagree (%)***	***Neither (%)***	***Agree (%)***	***Strongly Agree (%)***	***Mean/ Mode***
Acceptance	0	16.7	33.3	33.3	16.7	3.5/4
Usefulness for learning TCP/IP	0	0	50	50	0	3.5/4
Usefulness for concepts of subject	0	0	28.6	42.9	28.6	4/4
Similiarity with the real network in the laboratory	16.7	0	50	33.3	0	3/3
Usability for distance learning	0	16.7	16.7	50	16.7	3.7/4

TABLE II. SELECTED SURVEY QUESTIONS FROM KNOWLEDGE RESULTS

Topics	**Learning Opinion (from Q14-Q19)**				
	Strongly Disagree	***Disagree***	***Neither***	***Agree***	***Strongly Agree***
ETHERNET/ Adressing	0%	17%	50%	17%	17%
ARP/ICMP	0%	17%	33%	33%	17%
Routing	0%	17%	50%	33%	0%
Network devices	17%	0%	67%	17%	0%

On the one hand, in general, table I shows how the designed topologies by lecturers from GNS3 provide an acceptable user experience to simulate the computer networks behavior. And more specifically, table II shows the perception level of students about the learning achieved regarding to aspects about computer network and communications such as analyzing packet traffic in a network depending on communication protocol or configuration and control of network devices. The most repeated opinion among students have been 'Neither Agree Nor Disagree' like answer to learning opinion about Addressing, Routing and Network devices. In addition, the 50% of students are "Agree" or

"Strongly Agree" with the results of their learning about communication protocols as ARP and ICMP.

Overall, the evaluation of student opinion indicates that they have a positive perception, which promotes new implementations and virtualizations by the lecturers. This fact encourages to lecturers to extend this tool to other subjects with more students like degree studies (i.e. Computer Network in Computer Science in the same University).

On the other hand, specific skills, which the students should know, are evaluated from assessment exercises. In the experiments, each topic evaluated was ranked as a value between '0' and '10', where '10' and '9' is exceptional, between '5' and '8' is acceptable, and less than '5' indicates that the student has not achieved the minimum score to pass the subject. The lecturers use some questions in order to students resolve with GNS3 on homework. These questions are used to measure understanding and acquired skills by students. The scores are shown in Table III.

TABLE III. RESULTS OF THE EXPERIMENTS FROM ASSESSMENT EXERCISES

Experiment	**Student Assessments**				
	Mean	***Standard Deviation***	***Standard error***	***Skew***	***Median***
Ethernet/ARP	7.1	1.2	0.54	1.17	6.75
ICMP	7.6	1.9	0.87	-0.08	7
TCP	6.8	2.2	0.96	-2.03	8
ROUTING	5.6	3.2	1.43	-1.96	7

The knowledge acquired of five protocols, such as Ethernet (IEEE 802.3), ARP (Address Resolution Protocol), ICMP (Internet Control Message Protocol), IP (Internet Protocol) and TCP (Transmission Control Protocol), was evaluated. Also, we have evaluated the addressing and routing processes. While addressing is the process to identify interfaces of nodes in a network, Routing is the process to select the best paths in a network between two nodes according to the routing tables and the network topology. These processes are learned by means execution of commands which generate packets traffic and using commands which allow us to read the MAC and IP addresses, subnet and masks information from the interfaces of nodes in the network. All commands are specifics of operative systems in each node. Table III shows the results of student assessments about those protocols and aspects. There were a total of 7 students who participated in the assessments. The sample is small and consequently, the mean value or average is less significant than median value. The standard deviation is large and this fact may imply that the learning level depends on the previous studies of students which is very different (computer science, electric engineering, telecommunications engineering, etc.). Anyway, the scores always pass 5.5 points and 6.5 points according the mean and median values, respectively. Also, sometimes, the results are high within the acceptable rank, values 7 and 8 over 10.

IV. CONCLUSION AND FUTURE WORK

This paper has presented an assessment in progress of a virtual laboratory of computer networks, carried out with free simulation tools such as GNS3 and its libraries. GNS3 has allowed us to implement and simulate the topology very similar to real topology in the real laboratory but also it helps us to virtualize new topologies easily and quickly without economic cost of resources. Thereby, the students can develop new topology, test its performance and analyze their network devices behavior free of cost.

The study based on students' opinion and their assessment exercises shows that students comprehend basic topics of the subject almost like a real computer network laboratory. In addition, all experiments have been replicated and adapted to virtual laboratory successfully. Only some restrictions have been detected such as the inability to simulate some link layer protocols such as Token Ring or WiFi (IEEE 802.5-802.11).

Overall, the results of the study demonstrate a positive effect of virtualize computer networks laboratories on learning tasks among students with little knowledge of computer networks and TCP/IP architecture, particularly. We are now designing and implementing new virtual topologies to test more advanced concepts such as bridging, dynamic and adapted routing, load balancing between routers and other device networks or NAT configurations (Network Address Translation). The objective is to introduce these developments for learning in other subjects with more students and with more knowledge of networks (i.e. in Computer Science Degree).

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