

Usability of virtual network laboratory in engineering education and computer network course

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Abstract — The importance of educational process in the field of Computer Science and Information Technology industry, as well as the need for educating highly skilled computer network professionals implies the importance of its course syllabus and laboratory tools. This paper presents evaluation and analysis of virtual network laboratory based on virtualization technology. The virtual network laboratory architecture is shown together with the supporting laboratory exercises. Evaluation criteria for these laboratory exercises include: description of learning goals, adopted skills, compatibility with course syllabus and side knowledge, and additional skills. Lessons learned after the virtual network laboratory course, are gathered as well.

Detailed analysis of the skills and knowledge that students adopted in this environment is summarized. Also, overall usability estimation in education of various engineering profiles and related computer networking and communication courses is shown.

Keywords-component; Computer Network course; engineering education; virtual network laboratories; virtualization technology

I. INTRODUCTION

This paper addresses computer network courses within higher education as well as other forms of education that demand network infrastructure. There are numerous ways for adopting practical and functional knowledge about computer networks and systems. The first one is to use laboratories with real network equipment, which enable students to work in real network surrounding. The problems that can occur in this case are laboratories' cost and availability. Laboratories with real network equipment also have limited access, considering the simultaneous work for certain group of students.

The second way of teaching practice can help to overcome these problems. For example, software tools for network modeling and simulation can be used. They have simulated environment designed for analysis and behavior prediction of Information and Communication Technology Infrastructures, including applications, servers and network technologies. Simulation software tools available nowadays are:

- OPNET IT Guru software is used in thousands of enterprises and government institutions all over the world and, at approximately 500 universities for research and teaching purposes. It has academic and

commercial edition. Academic edition is discrete event network simulator in computer networks with great number of simulations and scenarios for education at universities. Commercial edition of software has even more possibilities and it is designed for enterprises, their infrastructure, documenting and professional support. [1]

- Ns-2 (Network Simulator) provides simulation interface for TCP/IP networks [2], routing and multicast protocols over wired and wireless networks. Ns-3 [1, 3, 4] is free discrete event network simulator [5] that is used for networking research and education.

Apart from above mentioned tools there are also: Bosom NetSim, Tetcos NetSim, OMNeT++, GNS-3, Cisco Packet Tracer and others.

This paper concerns the third way of teaching the computer network concepts. It has emerged in the last several years and suggested virtual network laboratories based on virtualization technology. Its rapid development is closely related to the virtualization software breakthrough on the market in the last few years. [6]

This paper describes model creation of virtual network laboratory (named VNLab) with remote access based on virtualization technology, together with its implementation and laboratory exercises, specially developed for this environment.

II. VIRTUAL NETWORK LABORATORIES

Virtualization software proved itself as efficient enough for virtual laboratories creation [7, 8, 9, 10]. These laboratories have multiple applications. The basic one is to create experimentation environment for new technologies, as well as developing and testing of network software. The next important application of virtual laboratories is in education of IT experts, i.e. for engineering education.

Virtual laboratories can be used in the fields of: operating systems [11], system administration and networks security [12, 13, 14, 15], server and client software development, data bases [16], distributed network platforms and other [17]. The most popular use of virtual laboratories is in the field of computer network education. There are many different

platforms developed for those purposes, as well as the ones primarily designed for experimenting and after for networking concepts studying.

Using both virtualization technology and appropriate software, virtual network environments, which completely corresponds to the real system, can be created. Virtualization enables creation of several virtual computers with different operating systems on one physical machine. Virtual computers can be servers, working stations and network units, such as router. Router's work can be totally emulated by virtual machine (VM) and specified software. Every virtual computer, i.e. virtual machine uses hardware of its physical computer. As every hardware component of the host computer, network interface card (NIC) is emulated too. Based on one physical card virtual machine can emulate many virtual network cards. There can be virtual connection between virtual machines and by that virtual network cards are connected in virtual network or its segment.

A. V-NetLab

V-NetLab environment represents complex structure with one NFS server. This server is used as storage for virtual machines and its disk image files. The V-NetLab has nine working stations with Linux operating system and VMware virtualization software. The system has gateway that enables users to access to the virtual network and command interface. [18]

B. VLabNet

This project is based on Debian operating system, Xen virtualization software and Quagga Routing Suite routing software. This solution represents one of the first attempts of combining virtual machines and physical network equipment. This laboratory integrates physical Cisco 2610 router as well. VLabNet is good example of virtual and classical routers application in laboratory creation. [19, 20].

C. Overview of some other network laboratories

Cloonix-Net (based on UML and KVM) and **GINI** (developed on Advanced Networking Research Laboratory at McGill University School of Computer Science). GINI (GINI is not Internet) is a development tool for micro virtual Internet environment, which can be used for teaching computer networks subjects [21]. It has simple graphical interface (gBuilder) for network instances creation.

VELNET (Virtual Environment for Learning Networking) [22, 23] – unlike other solutions developed on UML or Xen platforms, VELNET uses VMWare Workstation virtualization software with three guest operating systems (Windows XP, Windows NT Workstation, OpenBSD). In this case, Windows platform is dominant, in contrast to previous solutions with Linux as dominant environment. It was developed in 2003 at the University of Western Sydney, Australia.

Marionnet [24] – is virtual network laboratory which enables defining, configuring and running complex networks and their devices such as switches, hubs, routers and cables. Marionnet is free application created for Linux platform and based on UML and VDE [25] virtualization tools.

vBET system [26] – is based on UML. Users describe scenario by textually oriented specification language. Parser processes specification and generates a script. By running the script virtual node and virtual topology are created. Scenario may be canceled after the experiment. vBET language is similar to the NetML and MLN ones, because automation of running commands on virtual machines is not allowed.

Dynagen [27] – differs from abovementioned systems. This system is oriented to the creation of scenarios made of emulated Cisco routers, based on Dynamips technology. The advantage of this system is high level of scenario reality while its drawback is inability to emulate any other platform or node type (such as server or working station) beside Cisco router.

III. ARCHITECTURE OF VNLAB

VNLab is virtual network laboratory with remote access. It is also an online educational system that distributes learning material, as well as learning environment, using the network infrastructure. The laboratory is based on virtualization technology.

VNLab was developed during 2007 at Technical Faculty “Mihajlo Pupin”, University of Novi Sad, Serbia. It is used as teaching environment for Computer Network course for bachelor students at Information technology study program.

VNLab represents hardware-software model of virtual network laboratory [28]. Hardware components of the model are: VNLab server, student, teacher and administrator workstations and network infrastructure that enable remote access to the VNLab server. Due to the software components complexity they will be described further in more details.

VNLab is based on Microsoft Virtual Server 2005 R2 [29] virtualization software. At first VNLab is hosted on Microsoft Windows 2003 platform and web server Microsoft IIS 6.0 (Internet Information Server) [30]. Later, at the beginning of summer semester this year, the laboratory has been ported to the new platform with the Microsoft Windows 2008 and IIS7. Its architecture is presented in the Figure 1. Two listed software components create the basis for implementation, administration and utilization of the virtual laboratory. The virtual server 2005 allows creation of virtual machines configurations, as well as its virtual network connections.

The emulated network supports up to 60 virtual machines. This number is sufficient for creation of the virtual network scenarios used for learning networking concepts. Virtual machines emulate hardware and software of physical machines together with the network interface cards (NIC). The maximum number of emulated NICs per virtual machine is four.

Emulated network has two major types of virtual machines. The first type has a role of computers and routers (nodes), which create the core of the network. Those nodes are preconfigured in order to enable the functional network environment completely similar to the real systems. In the Figure 1 nodes are labeled as VM Node 1, VM Node 2, etc. Emulated nodes are designed to enable creation of virtual

network suitable for building the environment for students to learn network concepts and to upgrade their skills with practical work in the real systems. The reality of the emulated network and learning scenarios depends on the configuration of these nodes.

The second type of the nodes (Figure 1) refers to access nodes (VM AccessNode1, VM AccessNode2 etc.). Those

nodes have only basic configuration. During the exercise students remotely log on those nodes and configure them in order to make them functional parts of existing network. The configuration depends on the current learning topic. The core of the network must be designed and configured in a way to provide the same functionality for all students during the exercises.

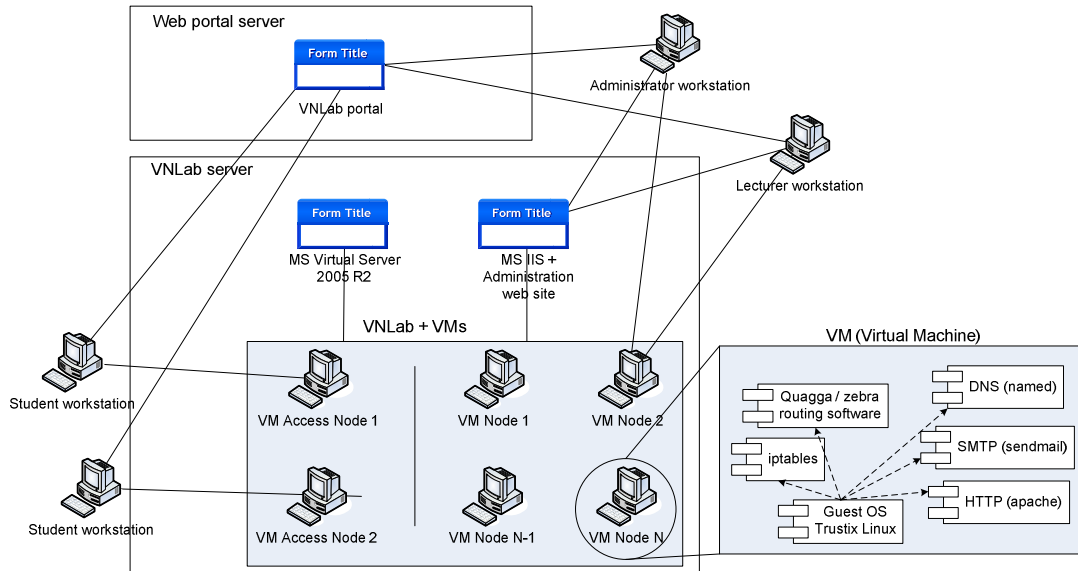


Figure 1. VNLab architecture

Remote access is provided by Microsoft software Virtual Machine Remote Console (VMRC) client software installed together with Virtual Server 2005 R2. It uses VMRC protocol for remote access to the virtual machines. The configuration of each virtual machine is the same. The Guest OS (operating system) installed on machine is GNU Linux. In the first version of the laboratory virtual machines had Trustix Linux 2.2. In the new, upgraded version of the laboratory, the newer versions of the operating system were installed. There are about 20 virtual machines with CentOS 6.2. operating system, with some experimental Scientific Linux workstations. The new workstations are used together with the old, but still functional machines with Trustix. The additional software is defined by multifunctional characteristics of the virtual machines. Depending on the scenario their role is to perform the task of: web, mail, ftp or DNS server, static and/or dynamic routing, firewall or to be a simple workstation.

In order to provide these functionalities all machines require installation of following software: apache as a web server [31], proftpd like a ftp server, Iptables for a firewall [32], sendmail as a mail server [33], GNU Zebra/Quagga like multiprotocol routing software, bind for DNS, c compiler etc. All listed software are used in the laboratory for the long time period and proved to be good. In case of utilization of some new kind of software (proxy or other server) any available open-source solution can be easily added to the existing platform.

Uniform software configuration of the virtual machines is not obligatory, but it is desirable because of initial

configuration of the laboratory, as well as its simple reconfiguration and alternative usage. All disks of virtual machines are disk image files, and after the installation of the first virtual machine, all other machines are added to the network by simple copying of the disk image. Its addition to the Virtual Server is provided in combination of IIS web server by administration web pages.

At the moment, in the VNLab environment exist about 60 virtual machines. The vital part of the system is its main hardware component – the VNLab server. The first configuration of the VNLab server was with low performance. It was Dell™ PowerEdge™ 800 server with CPU Intel Pentium 4 3.2 GHz, 1GB RAM-a, 150GB HDD and with Microsoft Windows Server 2003. This lower performance configuration has limited usage of up to 40 virtual machines, and limited the choice for the guest OS only to Trustix. One of the bottlenecks is RAM of the VNLab server. Trustix OS proved to be very efficient in working with only 16 MB RAM for virtual machines. The other bottleneck is processor usage and, again, the virtual machines acted well with only 5% CPU power assigned to the workstation and 20% of CPU power assigned to the router/server (core nodes). The feature of limiting percentage of CPU usage is allowed by the Virtual Server 2005 administration web site. The third bottleneck is disk space and Trustix OS provided fully functional Linux box with only 400MB disk images for each virtual machine.

In the beginning of this summer semester the VNLab is ported to the new platform with official usage of the lab. The

new lab is ported to the server with the following configuration: Intel Zeon CPU 2,6GHz, 16GB RAM, 120 GB HDD, Windows 2008. It provides the usage of new operating system. Virtual machines with CentOS 6.2 require 128MB RAM, and the same percentage of the CPU usage in the new environment. The size of disk image is increased to approximately 1.2GB. The server has enough capacity for large number of machines, much more than existing number of used virtual machines. Further development includes integration of additional OS in the laboratory (e.g. Scientific Linux, Microcore, SMS Linux, NetBSD etc.).

IV. THE LAB EXERCISES IN THE VNLAB

In order to make VNLab environment usable for Computer Network course and to adjust it to the lectures and curricula of the same course, 12 laboratory exercises are created. Most of exercises consist of three parts: the short introduction, programmed task and problems to solve. The introduction has a brief explanation of the topic to be learned, together with the terms needed for the exercise. The second part, the one with programming task contains step-by-step instruction how to log on the virtual machine and how to configure particular machine. The third part contains problem related to the exercise topic. Students solve this problem by configuring their machines. Only few tasks are not applicable on the virtual machines. Instead, students resolve their tasks on the paper.

Because of the short introductory part which is given at the beginning of the exercise and the concise explanation during the step-by-step configuration instruction, the required starting knowledge for the lab usage is limited only to brief OSI model and TCP/IP protocol basics.

The created exercises are presented in the Table I. There are: the code of the exercise, its name and set of learning topics, terms, concepts and commands covered by the exercises.

TABLE I. LIST OF VNLAB EXERCISES

| Lab | Lab exercise description |
|---------|--|
| VNLab00 | VNLab environment and LinuxOS |
| | introductory exercise, VNLab environment, Linux operating system, Linux file system, network settings, configuration files, commands: <i>ifconfig</i> |
| VNLab01 | IPv4 addressing and static routing – part 1 |
| | IPv4 addressing, IP address, netmask, network prefix, network address, broadcast address, routing introduction, static routing, commands: <i>route add, route del, route, netconfig, ping, traceroute.</i> |
| VNLab02 | IPv4 addressing and static routing – part 2 |
| | IPv4 addressing, IP address, netmask, broadcast address, static routing, network design, default route, commands: <i>route add, route del, route, netconfig, ping, traceroute.</i> |
| VNLab03 | IPv6 addressing and static routing |
| | IPv6, IPv6 addressing, global-unicast address, site-local address, link-local address, IPv6 static routing, 6to4 tunneling, ND protocol, commands: <i>route add, route del, route show, traceroute.</i> |
| VNLab04 | RIP routing protocol |
| | Dynamic routing, RIP protocol basics, Zebra/quagga multiprotocol routing software, Cisco IOS-like |

| Lab | Lab exercise description |
|---------|--|
| | environment, router configuration, commands: <i>router rip, passive interface, network.</i> |
| VNLab05 | OSPF routing protocol – backbone area |
| | Dynamic routing, OSPF protocol basics, interior gateway protocols, area 0 (backbone), path costs, Zebra/quagga multiprotocol routing software, Cisco IOS-like environment, commands: <i>router ospf, passive interface, network, area, ip ospf cost.</i> |
| VNLab06 | OSPF routing protocol – multiple areas |
| | Dynamic routing, OSPF protocol basics, interior gateway protocols, multiple areas, area types, path costs, Zebra/quagga multiprotocol routing software, Cisco IOS-like environment, commands: <i>router ospf, passive interface, network, area, ip ospf cost.</i> |
| VNLab07 | BGP routing protocol |
| | Dynamic routing, BGP protocol basic, exterior gateway protocols, Zebra/quagga multiprotocol routing software, Cisco IOS-like environment, autonomous system, neighbors, commands: <i>router bgp, network, neighbor.</i> |
| VNLab08 | Server software – part 1 |
| | TCP and UDP protocols and ports, server software, file <i>/etc/services</i> , starting and stopping services, commands: <i>netstat, telnet</i> ; programming simple client and server software, compiling and installing server software (source code), rpm packages |
| VNLab09 | Server software – part 2 |
| | Server software configuration, apache (web server), proftpd (ftp server), bind (DNS server) |
| VNLab10 | Firewall |
| | Firewall IPv4 principles, configuration, iptables, packet filtering, NAT, port forwarding, network and system security |
| VNLab11 | Firewall IPv6 |
| | Firewall IPv6 principles, configuration, iptables6, packet filtering, network and system security |

V. LABORATORY USABILITY

According to the categorization [34] of the leading world computing organizations IEEE (Institute of Electrical and Electronics Engineers), ACM (Association for Computing Machinery) and AIS (Association of Information Systems) in the post 1990 era there are five areas in the field of computer science: Computer Engineering (CE), Computer Science (CS), Information Technology (IT), Information Systems (IS) and Software Engineering (SE). All these categories have integrated course related to computer networks and the VNLab usability in the recommended curricula will be analyzed in the following section.

In the Information Technology undergraduate program, recommended by ACM and IEEE, VNLab is applicable within Networking (NET) course. The course covers 22 hours distributed in 6 learning modules. Following learning modules are supported in the VNLab environment [35]:

- NET. Foundations of Networking
- NET. Routing and Switching
- NET. Security
- NET. Network Management
- NET. Application Areas

Computer Science undergraduate program, recommended by ACM and IEEE, incorporates NC.Net Centric Computing

(18 hours). Apart from 3 core and 7 elective learning modules, following learning modules are supported with VNLab [36]:

- NC/Introduction [core]
- NC/NetworkCommunication [core]
- NC/NetworkSecurity [core]
- NC/NetworkManagement [core]

Computer Engineering, also recommended by the same organizations has Computer Networks (CE-NWK) course (7 core and 5 elective learning modules) [37]. The supported modules in the VNLab are:

- CE-NWK0 History and overview [core]
- CE-NWK1 Communications network architecture [core]
- CE-NWK2 Communications network protocols [core]
- CE-NWK5 Data security and integrity [core]
- CE-NWK9 Network management [elective]

The possibility of VNLab to support particular learning module is assessed by ability to cover part of learning module topics, learning outcomes and advanced learning objectives. The percentage of VNLab supportability particular module is hard to quantify.

Table II provides a comparative view of the emphasis on computing topics related to computer networks among the five kinds of degree programs covered. First number represents minimal and second number present maximal emphasis related to that topic.

Table II. Comparative weight of networking topics across the five kinds of degree programs

| Networking and communications | CE | CS | IS | IT | SE |
|-----------------------------------|-----|-----|-----|-----|-----|
| Net Centric Principles and Design | 1/3 | 2/4 | 1/3 | 3/4 | 2/4 |
| Net Centrix Use and Configuration | 1/2 | 2/3 | 2/4 | 4/5 | 2/3 |

In the Table III are listed 8 performance disciplines in the category of the computer networks. Each discipline has been assigned a value from 0 to 5. The value 0 represents no expectation whatsoever, while 5 represents the highest relative expectation.

The virtual network laboratory VNLab and its lab exercises are applicable in the disciplines of designing network configuration, install computer network, manage computer network and implement communication software.

Table III. Expectations of the performance abilities for the area of computer networks

| Networking and communications | CE | CS | IS | IT | SE |
|---------------------------------|----|----|----|----|----|
| 1. Design network configuration | 3 | 3 | 3 | 4 | 3 |
| 2. Select network components | 2 | 2 | 4 | 5 | 2 |
| 3. Install computer network | 2 | 1 | 3 | 5 | 2 |
| 4. Manage computer networks | 3 | 3 | 3 | 5 | 3 |

| Networking and communications | CE | CS | IS | IT | SE |
|---|-------------|-------------|------------|-------------|----------|
| 5. Implement communication software | 5 | 4 | 1 | 1 | 4 |
| 6. Manage computer resources | 1 | 0 | 3 | 5 | 0 |
| 7. Implement mobile computing system | 5 | 3 | 0 | 1 | 3 |
| 8. Manage mobile computing resources | 3 | 2 | 2 | 4 | 1 |
| Average number of points (1+3+4+5) | 3,25 | 2,75 | 2,5 | 3,75 | 3 |

According to this observation, the VNLab has its highest usability for the Information Technology course where the average expectation grade for required disciplines is 3.75 and after that for Computer Engineering (3.25) and Computer Science (2.75).

VI. CONCLUSION AND FURTHER WORK

In this paper is presented VNLab – the virtual network laboratory with remote access based on virtualization technology. VNLab has been developed at Technical Faculty “Mihajlo Pupin” – Zrenjanin, University of Novi Sad. The laboratory is used as a main teaching tool for laboratory exercises in Computer Network course in education of bachelor students for Information Technology degree. The VNLab has been used since school year 2007-2008 now, for approximately 50 students divided in three groups per year. The lab exercises are held during one semester in a period of 90 minutes class.

During the whole period of usage, there were no major problems with laboratory functionality. VNLab proved itself to be flexible and stable system, ease to use by students and easy to manage by the administrator /teacher.

The analyses in the previous section showed that the VNLab is usable in the Computer Network related courses primary for Information Technology curricula, but also in a smaller extent for Computer Engineering and Computer Science Curricula.

In the future work the major goal will be extension of learning modules covered by VNLab for all five computing undergraduate degree programs. The additional effort may be pointed toward adaptation of VNLab environment for use in laboratory exercise in subject related to distributed systems, operating system, computer security etc.

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