Virtualization Technology as a Tool for Teaching Computer Networks

Dalibor Dobrilović, and Borislav Odadžić

***Abstract*—**In this paper is being described a possible use of virtualization technology in teaching computer networks. The virtualization can be used as a suitable tool for creating virtual network laboratories, supplementing the real laboratories and network simulation software in teaching networking concepts. It will be given a short description of characteristic projects in the area of virtualization technology usage in network simulation, network experiments and engineering education. A method for implementing laboratory has also been explained, together with possible laboratory usage and design of laboratory exercises. At the end, the laboratory test results of virtual laboratory are presented as well.

***Keywords*—**Computer network simulation software, teaching networking concepts, virtual network laboratory, virtualization technology.

I. Introduction

TEACHING computer network concepts is hardly possible without having specialized network laboratories or some other tools suitable for such course. In recent time there have been new methods and technologies used for adopting new and efficient tools in teaching computer networks. All attempts have been made in order to eliminate as many disadvantages of specialized laboratories as possible. What can be the principal disadvantages of real networking laboratories? First, there are very expensive. Then, it is also necessary to invest a great deal of money to upgrade such laboratories. In addition to that, such laboratories are not flexible because they are not appropriate for a variety of network topologies. And above all, those laboratories can be used by only a small number of students in the same time, because of the strictly physical limitation (only two or three students per computer).

The alternative way of teaching computer networks and networking concepts could be simulation software. This approach may be very useful, because it is efficient way to simulate both small and large networks with different technologies and topologies as well. There are several network simulation tools such as OPNET IT Guru Akademic Edition™ [1], Network simulator NS–2 or Boson NetSim™. The only problem with such type of software is the fact that students are not completely involved in real configuration of network equipment and networks and don’t have enough operating experience.

The question is; is there alternative? Nowadays, when there are many emerging technologies, one particular technology appears to be very suitable for computer network simulation and therefore also very appealing for creating virtual laboratories for computer network courses.

II. Virtualization Technology

The base of virtualization technology is a virtual-machine monitor (VMM). “VMM is a layer of software that emulates the hardware of a complete computer system. The abstraction created by the VMM is called a virtual machine [2]”. Although first virtual machines were developed and used since 1960s (best-known example is IBM’s VM/370), commercial virtualization software is only present on the market for several years. Connectix (today Microsoft) Virtual PC was introduced in 1997; VMware Workstation in 1999 and VMWare GSX Server and ESX Server products were introduced in 2001. It is interesting to say that in the beginning, when the hardware was very expensive, virtualization technology was very popular. Decline of

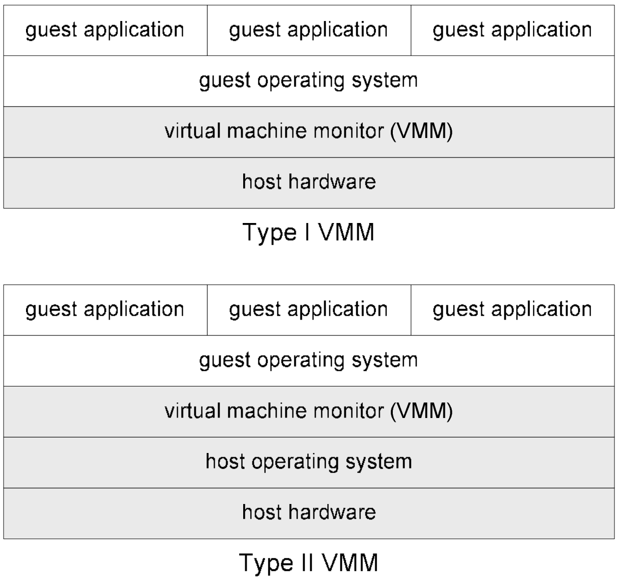

Fig. 1 Virtual machine structures

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popularity came with the significant decreasing of the hardware costs. Nowadays, virtualization is popular again.

Virtualization was initially developed to enable emulation of multiple virtual computers on a single physical computer. Emulated computer, generally speaking, can have installed any other operating system and act as totally independent node. A Virtual computer, called virtual machine, uses existing hardware on a physical machine. Being capable of emulating several network cards on single physical network card, emulated computers may be used to establish virtual network communication and to simulate virtual networks.

All software packages in virtualization technology domain can be divided in the three categories, according to their structure (Fig. 1) or host platform on which they are built [2,3]. Type I VMMs (stand-alone) are implemented directly on the physical hardware (examples are IBM's VM/370, VMware's ESX Server). Type II VMMs (hosted) are built completely on top of a host operating system (User-Mode Linux). Third group of VMMs are a hybrids between Type I and II. They operate mostly on the physical hardware, but they use host OS to perform I/O operations (VMware Workstation, Microsoft Virtual PC, Virtual Server 2005).

Also, virtualization software can be divided in two categories according to software usage:

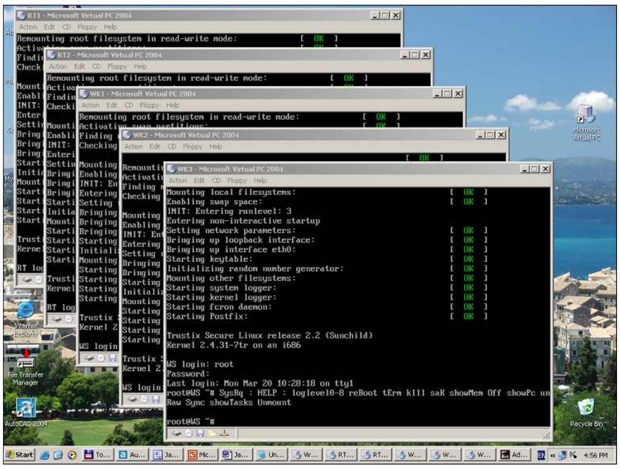
- *Server type software* – software designed for remote access and control of virtual machines (Microsoft Virtual Server 2005 and VMWare Server GSX)
- *Single user type software* – software designed for being used on the single computer separately (Miscrosoft Virtual PC 2004, VMWare Workstation 5.5 and Xen).

Virtualization software is suitable for creating virtual network laboratory. Analyzes of various virtual netwok laboratory projects can easily prove it.

III. Virtual Network Laboratories

For the past few years there have been several projects with basically the same goal. The idea was to use virtualization technology as a basic tool for realization of virtual network laboratory. Virtual laboratories created in this way have several purposes such as experimental networking for IPv6 protocol, educational and experimental purpose and research.

- **VNUML** (Virtual Network User Mode Linux) is open-source tool for virtualization. It was designed to simulate computer networks. This tool is based on User Mode Linux (UML) and was developed in 2004. at Telematics Engineering Department - DIT (Technical University of Madrid – UPM) as a part of Euro6IX research project for IPv6 network simulation with zebra/quagga open-source routing software [4].



RT1 - Microsoft Virtual PC 2004
RT2 - Microsoft Virtual PC 2004
WK1 - Microsoft Virtual PC 2004
WK2 - Microsoft Virtual PC 2004
WK3 - Microsoft Virtual PC 2004
Action Edit CD Floppy Help
Start
Recycle Bin
4:56 PM

```
Mounting local filesystems:                          [  OK  ]
Enabling swap space:                                 [  OK  ]
INIT: Entering runlevel: 3
Entering non-interactive startup
Setting network parameters:                          [  OK  ]
Bringing up loopback interface:                      [  OK  ]
Bringing up interface eth0:                          [  OK  ]
Starting keytable:                                   [  OK  ]
Initializing random number generator:                [  OK  ]
Mounting other filesystems:                          [  OK  ]
Starting system logger:                              [  OK  ]
Starting kernel logger:                              [  OK  ]
Starting fcron daemon:                               [  OK  ]
Starting Postfix:                                    [  OK  ]

Trustix Secure Linux release 2.2 (Sunchild)
Kernel 2.4.31-7tr on an i686

WS login: root
Password:
Last login: Mon Mar 20 10:28:18 on tty1
root@WS ~# SysRq : HELP : loglevel0-8 reBoot tErm kIll saK showMem Off showPc un
Raw Sync showTasks Unmount

root@WS ~#
```

Fig. 2 Virtual network laboratory with several virtual machines started

- **Netkit** is environment initially aimed for experimental usage in the area of computer networks. NetML (the XML-based language) is designed for network topology description. Netkit is based on open-source software and on User Mode Linux. Project started in 2005. at Computer Networks Research Group (University of Roma Tre) as a part Linux User Group LUG Roma 3 in order to create low-cost environment for education [5].
- **Imunes** is research tool designed for research in computer networks and distributed systems area. This network emulator is based on modified FreeBSD kernel. Project started 2003. at Electrotechnical Faculty (FER) – University of Zagreb. It was part of development project for Ethernet, routing and IPv4 and IPv6 networks simulation [6].
- **Einar** is router simulator, available as live CD. It was developed for the education purposes and for teaching routing concepts. Project was developed at Royal institute of technology (Sweden). It is based on Knoppix platform with Xen virtualization software and Quagga routing software [7].
- **VELNET** (Virtual Environment for Learning Networking) is virtual laboratory for computer network classes based on VMWare Workstation software and various guest operating systems (Windows XP, Windows NT Workstation, OpenBSD). Developed in 2003. at School of Computing and Information Technology (University of Western Sydney, Australia). There are several projects like this one [8].

IV. Virtual Laboratory Implementation

In this paper will be described a method for implementation of virtual network laboratory at Technical Faculty "Mihajlo Pupin" of Zrenjanin (University of Novi Sad, Serbia & Montenegro). The implementation is based on described experience from other research project. A designed virtual network laboratory has to meet several special requirements.

The laboratory is planned to be used in a computer network course for teaching IP addressing, static and dynamic routing (RIP and OSPF), firewall concepts and for teaching network services (Web and FTP). It has to be low-cost and easy-to-use solution and based on the Windows XP platform, because the same real computer laboratory is used for several other courses, all based on Windows platform.

Software tools for projects realization are limited on VMWare and Virtual PC, because of the previous requirements. Without testing another option, Microsoft Virtual PC 2004 [9] was choused because of the licensed version. The next question is what can be appropriate for guest operating system on virtual machines. Guest OS has to be installed on each virtual machine separately, and may differ from basic operating system (Windows XP). Considering that the basic plan is to develop a low-cost environment the logical choice is Linux or another open–source operating system (Figure 1.).

There are several Linux distributions, suitable for the use. One of the operating system tested in this research was Trustix Linux Server. It is compact operating system with small installation and low hardware requirements and, especially, low memory requirements.

All remaining software necessary for the complete and required network simulation is available on the chosen platform. Linux has variety of software packages desirable for lab exercises. For IP addressing could be used standard Linux commands *ifconfig* and *netconfig*. Static routing could be done with *route* commands. Firewall concepts can be realized with usage of *iptables* software installed as a package together Linux OS.

TABLE I
Virtual Network Laboratory Exercises Structure

Lab	Topic	Virtual machines	Software
1	IP addressing	RT1	ifconfig, netconfig
2	static routing	WS1, WS2, RT1, RT2, SRV1	route command
3	RIP protocol	WS1, RT1, RT2, RT3, RT4, SRV1	zebra routing software
4	OSPF protocol, one area	WS1, RT1, RT2, RT3, RT4, RT5, SRV1	zebra routing software
5	OSPF protocol, stub areas	WS1, RT1, RT2, RT3, RT4, RT5, SRV1	zebra routing software
6	Web service FTP service	WS1, RT1, RT2, SRV1	apache web server, proftpd
7	firewall concepts	WS1, WS2 RT1, RT2, SRV1	iptables

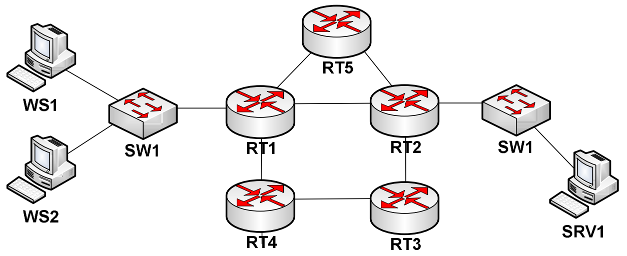


Fig. 2 Virtual network laboratory topology

One of the most important questions is how to organize dynamic routing exercises. Using various free routing software suits can do it. There are many available and stable open-source software solutions on the market such as Zebra, Quagga and XORP. The software used in the described exercises is GNU Zebra free routing software, with support for RIP, OSPF and BGP4 dynamic routing protocols [10].

Finally, it was not hard to chouse the right server software for teaching Internet services. Like in other cases there many open-source solutions, and it was easy to implement one of them. The choice was an Apache server for web service and proftpd for FTP service. In both cases it is widely used and reliable open-source software.

After completing the installation, virtual machines with Linux OS and all required software were tested during the start-up and laboratory exercises. They were very trustworthy and satisfying software combination for the described exercises. Test results are shown in the following chapters.

For the laboratory exercises it was obligatory to install and start-up all virtual machines on every single PC in the real computer laboratory where the exercises are taking place. All used virtual machines can be formed on a single PC used for preparation of the environment. After that, the formed virtual machines can be copied to all others computer in the classroom.

V. Laboratory Exercises

The next step is creation of laboratory exercises for designed virtual laboratory. At this stage it is required to plan and design network topology for all exercises. Considering the lab exercises structure and course needs the most suitable virtual network topology is show in the Figure 2. The network needed for exercises has 5 routers (RT1, RT2, RT3, RT4 and RT5), 2 workstations (WS1 and WS2) and 1 server (SRV1), total number of 8 virtual machines.

Seven laboratory exercises have been tested during the course of computer networks at Technical Faculty “Mihajlo Pupin” in Zrenjanin. Each exercise description, including covered topics and required software components are given in the table bellow (Table I).

It might be interesting to say that Zebra routing software, used in dynamic routing protocol exercises (RIP and OSPF), and has similar CLI like Cisco routers. Example router configuration is given below (Listing 1).

```
ospfd> enable
ospfd# configure terminal
ospfd(config)# router ospf
ospfd(config-router)# passive-interface eth3
ospfd(config-router)# network 192.168.11.0/24 area 1
ospfd(config-router)# network 172.16.14.0/30 area 1
ospfd(config-router)# network 172.16.15.0/30 area 1
ospfd(config-router)# network 172.16.12.0/30 area 0
ospfd(config-router)# area 1 stub no-summary
ospfd(config-router)# exit
ospfd(config)# interface eth0
ospfd(config-if)# ip ospf cost 5
ospfd(config-if)# exit
ospfd(config)# interface eth1
ospfd(config-if)# ip ospf cost 20
ospfd(config-if)# exit
ospfd(config)# interface eth2
ospfd(config-if)# ip ospf cost 10
ospfd(config-if)# exit
ospfd(config)# write
Configuration saved to /usr/local/etc/ospfd.conf
ospfd(config)# exit
ospfd# exit
Connection closed by foreign host
```

Listing 1 Example of router configuration
with Zebra routing software

In teaching Internet services (lab exercise 6) students are able to learn how to compile and install server software (apache or proftd), or to do step-by-step configuration of Web and FTP services. At the end, student may access the service and analyze server logs.

VI. Virtual Laboratory Testing

Virtual laboratory was tested on two different computer configurations. The measurements were performed with Microsoft ® Management Console. The main performance measured was processor use at the time of start-up and during the exercise. Also, memory and hard disk space usage were measured. The computer performance tests are given in the Table II. NVM column shows number of virtual machines used during the lab scenarios. 7 XP is scenario with one virtual machine running RedHat 9.0 with X-Windows instead of minimized installation of Trustix Linux installed the on other machines. The RedHat workstation has considerably larger virtual disk file size, 2,58 GB comparing to approximately 400 MB of Trustix file size. In addition, memory usage of RedHat virtual machine is 128 MB, comparing to 16 MB RAM of virtual machines with Trustix OS. Working with the X-Windows virtual machine was much slower, but possible.

TABLE II
Computer Performance Test

C	NVM	ST	PU	PMU	HDU
C1	1	~1	7-38	329	0.39
C1	5	~2	15-73	199	1.92
C1	6	~4	16-76	168	2.31
C1	7	~5	31-88	137	2.70
C1	7 XP	~6	47-100	91	5.33
C2	1	~1	7-48	331	0.39
C2	5	~3	56-95	225	1.92
C2	6	~5	58-97	194	2.31
C2	7	~6	72-100	169	2.70
C2	7 XP	~7	79-100	68	5.33

C = Computer configuration; NVM = Number of virtual machines; ST = Start-up time (min); PU = processor usage during exercise (percentage); PMU = Physical memory available (MB); HDU = hard disc usage (GB).

C1 = Windows XP workstation with Intel Celeron 2,66GHz CPU and 512MB of RAM; C2 = Windows XP workstation with Intel IV 1,5GHz CPU and 512MB of RAM

Another testing of virtual laboratory performance was done after the completed exercises. The questionnaire was completed by the students participated in exercises (total number: 79). There were three questions in the questionnaire. First, the students were asked to rate usage of Virtual PC 2004 software in Computer network course. Second, the students were asked to grade how much was this approach in teaching networking concepts useful in their opinion. And third, the students were asked to grade how much was the same approach useful in preparing them to work with real systems. Grades were in the range from 1 to 5, with 5 as the best grade. Results (average grade) of the questionnaires are given in the Table III.

The students were very satisfied with usage of virtualization software Virtual PC 2004 in the teaching course. The average grade is high – 4.19 and almost 40% of students (31) gave the highest mark and about 43% gave grade 4 (34).

The students were less convinced that this method could teach them networking concepts. But the average belief is rather high –3.95. It is interesting to point out that the number of student with grade 4 is practically the same, but there was a decrease in number of student willing to give grade 5 (about 27% or 22 students). According to the average grade (3.55) of the third question, the students were the least convinced that this approach could prepare them to work with real network systems. Even lesser number of students gave highest grade 5 (15% or 12 students) then in the previous cases.

TABLE III
QUESTIONNAIRES RESULTS

Q	AG	N5	N4	N3	N2	N1
Q1	4.19	31	34	12	2	0
Q2	3.95	22	35	18	4	0
Q3	3.56	12	34	23	6	4

Q – Question; AG – Average Grade; N5 – number of given grade 5; N4 - number of given grade 4; N3 - number of given grade 3; N2 - number of given grade 2; N1 - number of given grade 1.

Q1 - Virtual PC 2004 software usage in computer network course; Q2 - What students think about possibility to teach network concepts with Virtual PC software?; Q3 -What students think about possibility to prepare themselves to work with real network systems with Virtual PC software?

VII. CONCLUSION

According to the test above, it is possible to create laboratory exercises based on virtualization technology to teach networking concepts. Basic tool for virtual network laboratory was user virtualization application – Virtual PC 2004. Linux is used as the virtual machine operating system. All other software used in virtual laboratory is open-source software. Hardware requirements were not so high and it is possible to create virtual laboratory usable for laboratory exercises on a computer with average characteristics.

For any future work priority has to be adaptation and improvement of new lab exercises, which will seam more realistic to the students. The control lab exercises have to be created to control and evaluate the level of students' knowledge achieved by using the described method. One of possible directions in the future work may be expansion of areas covered with lab exercises and finding suitable network scenarios for the computer network and other courses such as distributed systems or operating systems.

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