

## A computer network laboratory based on the concept of virtual machines

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**ABSTRACT:** Courses in computer networks require dedicated laboratories that are equipped with all the basic networking components: servers, workstations, cables, switches, routers, bridges, etc. An important element of a laboratory's infrastructure is a variety of network configurations for specific experiments. A possible method of disseminating network configurations is a dedicated server. The server stores appropriate disk images, which can then be downloaded to student computers. An interesting and cost-effective alternative is the concept of *virtual machines*. Students do not waste time on reinstalling operating systems or rebooting computers and gain fast access to a selection of network configurations from local computers. In addition, complex experiments, such as analysing network protocols and services, securing confidential information transmitted over the Internet and testing redundant disk systems, can be implemented on a single computer without the need for the usual hardware components, such as cables, network cards, switches or multiple disk drives. Virtual machines are an ideal solution in distance education, as well as for universities and colleges with limited financial resources.

### INTRODUCTION

In this article, the author describes the benefits of virtual machines and virtual networks for on-campus and distance education, as well as industry-based training. A course in computer networks needs to be supported by a dedicated laboratory equipped with various networking components, such as servers, workstations, cables, switches, routers, bridges, etc. An important element of the laboratory infrastructure is a variety of network configurations for specific experiments. A possible method of disseminating network configurations is a dedicated server. The server can store appropriate disk images, which can then be downloaded to student computers.

Two of the dedicated server drawbacks, ie delays caused by network congestion and the costs of technical support, can be eliminated by applying the concept of virtual machines. Virtual machine software, such *VMware* or *Virtual PC*, allows students to run multiple operating systems and a variety of network configurations on a single computer [1][2]. The reinstallation of operating systems can be accelerated and students gain fast access to a selection of network configurations from local computers. Students can create virtual networks from a single PC and carry out advanced networking experiments, including analysing network protocols and services, protecting transmission of confidential information over the Internet, and testing redundant disk systems.

### THE CONCEPT OF VIRTUAL MACHINES

It should be stressed that virtual machine software does not simulate the operation of a physical personal computer. The software uses a *virtualisation layer* to run a number of virtual machines (computers) on a single physical PC known as a *host computer* (see Figure 1). Each virtual machine operates like an ordinary PC and has the following characteristics:

- Shares physical resources, such as Random Access Memory (RAM) of the host computer;
- Runs its own operating systems called *guest operating system*;
- Runs standard applications software, eg word processor;
- Can be connected to virtual or physical input/output devices;
- Stores data on virtual or physical (recommended for advanced users only) disks;
- Can be allocated a unique IP (Internet Protocol) address and communicates with virtual or physical computers utilising standard protocols and services.

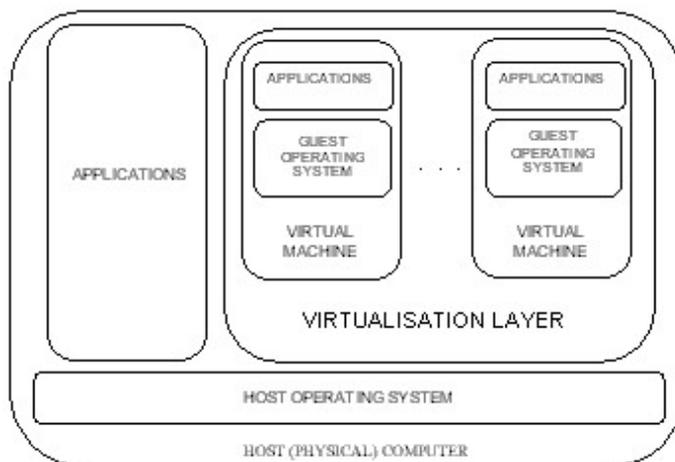


Figure 1: Host computer running virtual machines.

The concept ensures that user interfaces of virtual machines and physical computers are undistinguishable.

Figure 2 is an example of a Windows XP host computer running four virtual machines concurrently.

The four virtual machines running concurrently, as shown in Figure 2, are as follows:

- Two Windows 2003 Servers (DC1 and DC2) configured as domain controllers;
- A Windows 2003 Member Server (MS1) configured as a router to link two network segments;
- A Red Hat Linux workstation to investigate connectivity options between Windows and Linux computers.



Figure 2: Host computer concurrently running two Windows 2003 domain controllers, a Windows 2003 router and a Linux workstation.

The maximum number of concurrently running computers is determined by the capacity of Random Access Memory.

Advanced experiments require at least 512 megabytes. Students, who try to combine Windows and Linux in a single multi-boot physical computer, will undoubtedly replace multi-booting by the lower risk alternative: virtual machines.

### THE CONCEPT OF VIRTUAL NETWORKS

Users of the virtual machine software can run concurrently several virtual computers and link them into a relatively complex virtual network. Figure 3 is an example of a virtual network that has been implemented on a single laptop computer with one gigabyte RAM. The network consists of Class A and Class C segments, linked together by a Windows 2003 server, configured as a router using the Routing and Remote Access Service (RRAS). Two Windows 2003 domain controllers have been introduced for advanced experiments, such as planning the Active Directory or implementing a fault-tolerant distributed file system. The virtual network shown in Figure 3 can be linked with a physical Local Area Network (LAN) of the student or even the Internet. Such a connection would require changes to the virtual switches VMnet [1]. For example, a predefined switch *VMnet0* links virtual machines to a physical network (bridged networking). Each virtual machine must be allocated a unique IP (Internet Protocol) address. The predefined switch *VMnet8*, similarly to VMNet0, links virtual machines to a physical network, although the Network Address Translation (NAT) protocol eliminates the requirement of a unique network identity for every virtual machine.

### EXAMPLES OF STUDENT EXPERIMENTS

The following examples of student activities can be implemented using the virtual network displayed in Figure 3.

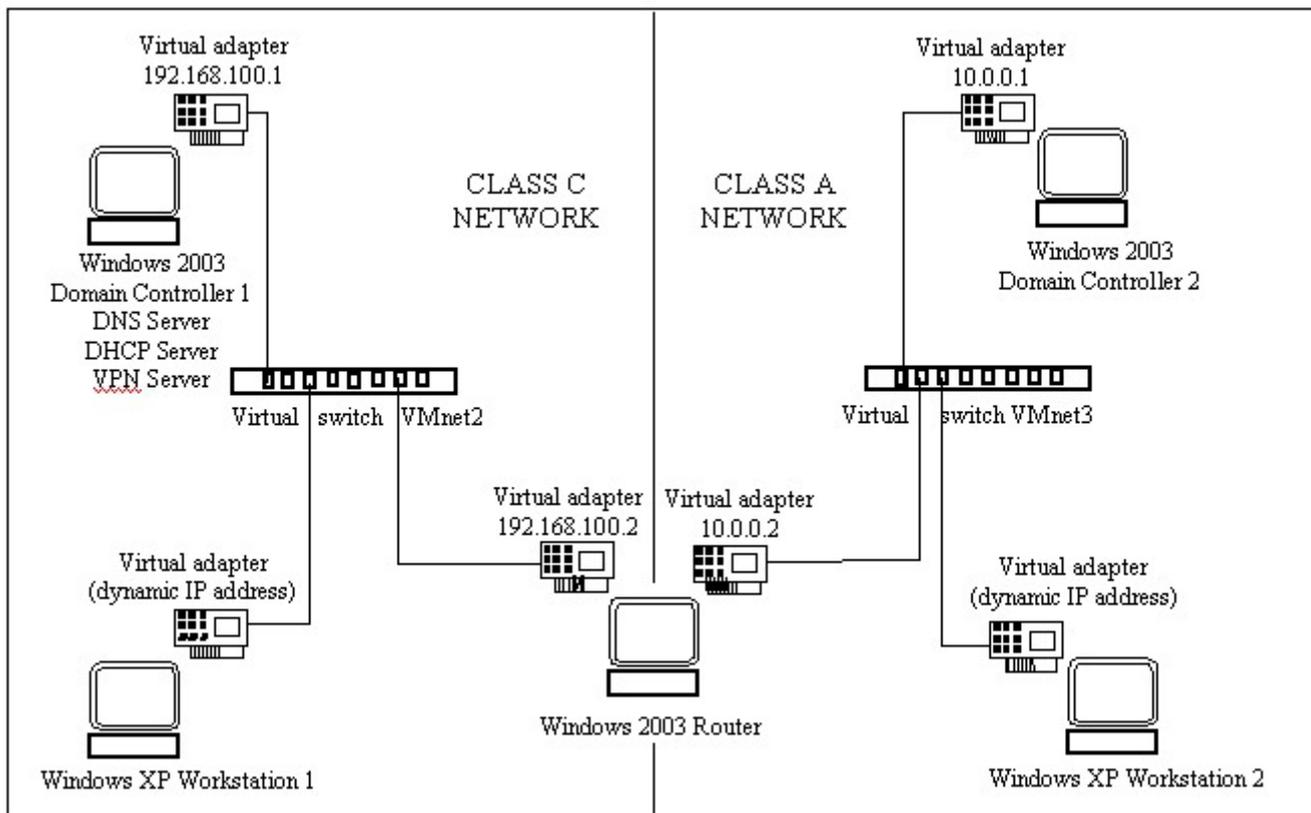


Figure 3: Virtual network with two network segments, a router, two domain controllers and two workstations.

## Dynamic Host Configuration Protocol (DHCP)

The Dynamic Host Configuration Protocol (DHCP) service is used to automatically configure the Internet Protocol (TCP/IP). Students are required to install and configure DHCP on one of the servers. They must create address scopes for two network segments and ensure that the DHCP server is accessible by the remote client computers. A correct IP address allocation to the remote client ws2.SCIS.EDU.AU (see Figure 4) confirms that the required routing protocol (DHCP Relay Agent) has been correctly installed and configured.

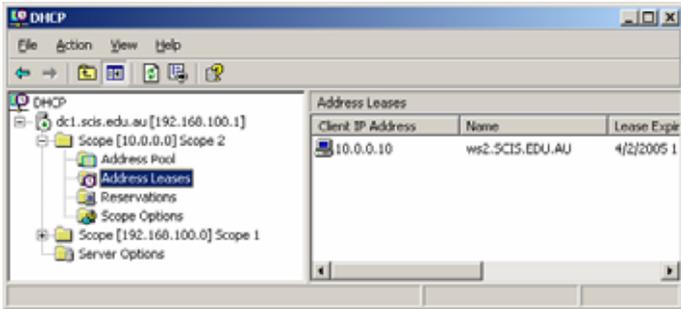
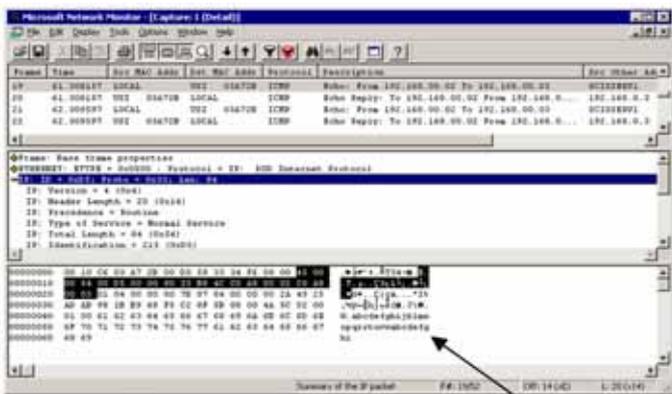


Figure 4: Confirmation that the DHCP server has allocated a correct IP address to a remote workstation.

## Implementing and Monitoring the IPSec Protocol

IPSec (Internet Protocol Security) is a set of communication standards providing the sender's authentication, data integrity and data encryption. Students' tasks include the implementation of the IPSec protocol and installing a network monitor. The monitor in Figure 5 clearly indicates that the medium IPSec security level may provide user authentication and data integrity, but not data encryption. Clear text data *abcdefg...* are visible in the monitor window.



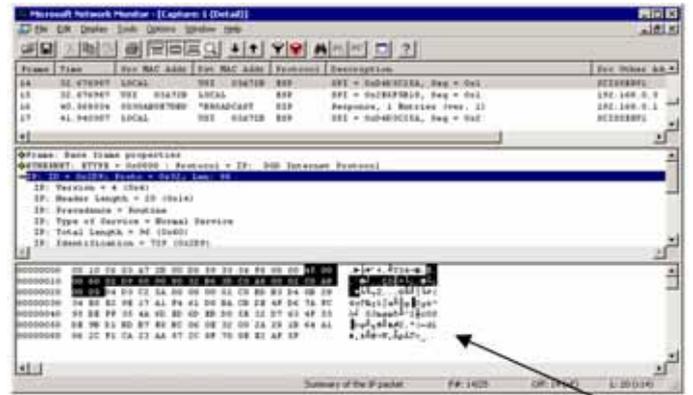
Clear text data of the Ping command

Figure 5: Monitoring the IPSec traffic.

As the next step, students are requested to achieve data encryption by switching to the high IPSec security level, as shown in Figure 6.

## Virtual Private Network (VPN)

Students learn how to create a secure communication channel within the public Internet. The task requires a pretty complex configuration of a VPN server, allocating the necessary permission to the selected domain user accounts (Figure 7) and configuration of client computers (Figure 8).



Encrypted Data

Figure 6: Encrypting data by switching to the high IPSec security level.

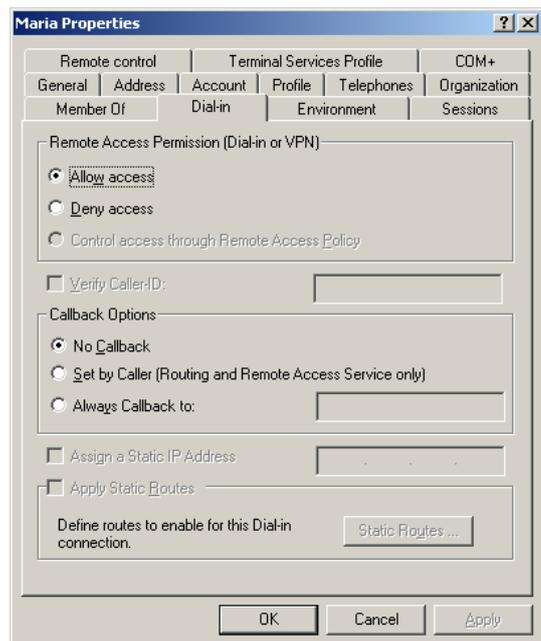


Figure 7: Allocating remote access permission to a domain user.



Figure 8: Confirmation at Workstation 2 that a domain user is connected to the Virtual Private Network (VPN).

Finally, students display a list of connected VPN clients at the VPN server (see Figure 9).

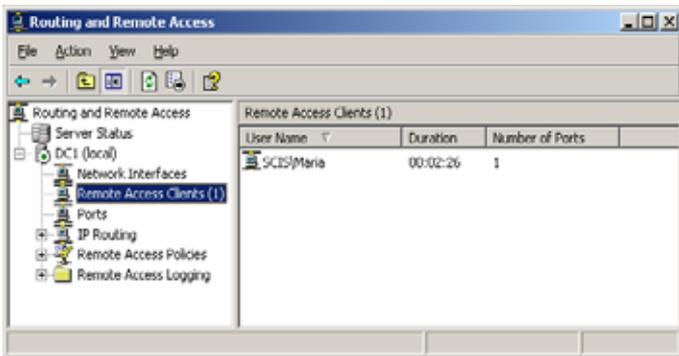


Figure 9: Listing of remote access clients at the VPN server.

### Installing a RAID-5 Disk System

Windows 2000 and 2003 introduce the so-called dynamic volumes, giving the network administrator the choice between five options for the hard disk system, as follows:

- Simple volume: provides disk capacity from a single disk drive;
- Spanned volume: integrates disk capacity of up to 32 disk drives;
- Striped volume: optimises performance by combining free space from up to 32 disk drives;
- Mirrored volume: requires two disk drives to provide fault tolerance;
- RAID-5 volume: requires between three and 32 disk drives to provide performance optimisation and fault tolerance.

Students can experiment with all five volume types with no need for additional hardware. Physical disk drives are replaced by virtual ones (see Figures 10 and 11).

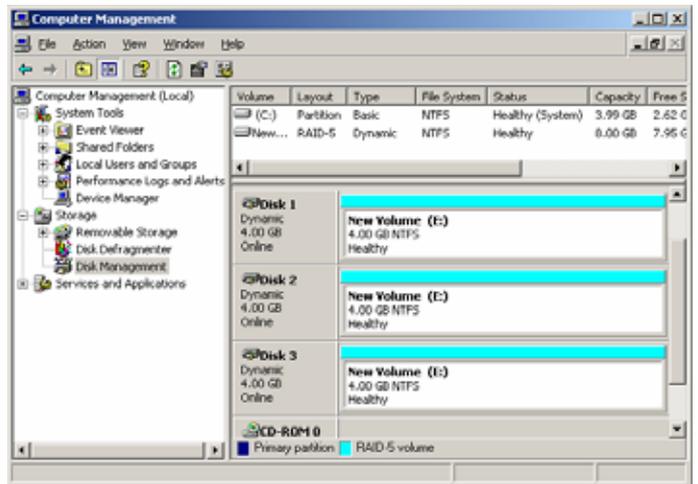


Figure 11: Confirmation that a RAID-5 volume has been created.

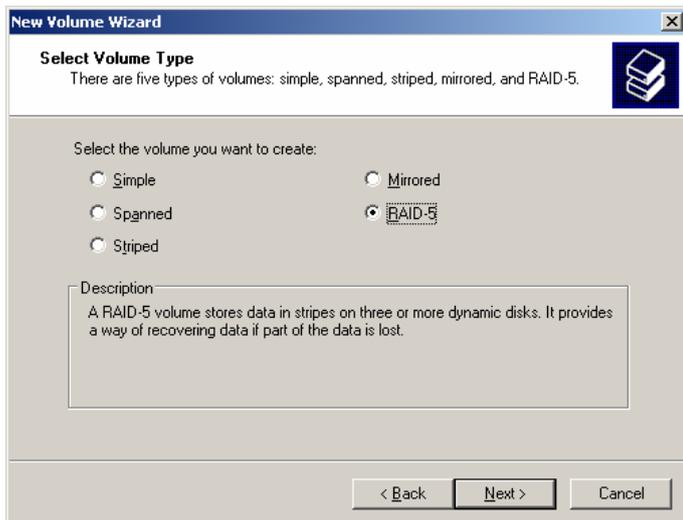


Figure 10: Choosing between five types of a dynamic volume.

### CONCLUSIONS

- The concept of Virtual Machines offers a range of challenging student experiments at the cost of a single PC and inexpensive virtual machine software. Virtual networks are sufficiently complex for university courses or industry-based certification programmes, such as Microsoft Certified Systems Engineer (MCSE). They can be easily linked with physical networks, including the Internet.
- Virtual machines and virtual networks have been successfully applied in the dedicated networking laboratories of the School of Computer and Information Science at Edith Cowan University (ECU), Perth, Australia. The concept has been particularly useful for the ECU courses running in Drogheda, Ireland and Beijing, China.
- There are undeniable advantages of virtual machines and virtual networks in distance education [3].
- The significance of virtualisation is not restricted to education. Other applications include software development and testing, plus no cost, no risk hardware testing [4].
- Finally, the more advanced versions of virtualisation software, such as VMware ESX Server or Microsoft Virtual Server 2005, can be applied for consolidation of multiple servers aimed at better server utilisation, streamlined software development or improved disaster recovery mechanisms [1][2].

### REFERENCES

1. <http://www.wmware.com>
2. <http://www.microsoft.com/virtualpc>
3. Kuczborski, W., The significance of virtual computer networks in distance education. *Proc. 6<sup>th</sup> UICEE Annual Conf. on Engng. Educ.*, Cairns, Australia, 163-166 (2003).
4. Kuczborski, W., The significance of the VM software in mechatronics. *Proc. 5<sup>th</sup> Inter. Workshop on Research & Educ. in Mechatronics (REM2004)*, Kielce, Poland, 29-32 (2004).