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An Overview of Network Simulation Tools in Teaching Computer Network

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Abstract –
Computer network technologies have been growing explosively. Teaching computer networking principles can be enhanced using simulation through the use of interactive (not statistical based) simulation. The curriculum is based on the theory that through networking simulation programs, students are able to graphically implement the concepts learned in their coursework. With networking simulation tools, students can construct, tune, and analyze network performance while reinforcing their understanding of networking theory. Network simulation tools save money by offering the user a tool to enhance the design and integration of networks. There are many network simulation tools that allow users to model LANs, MANs, and WANs on the market. In this work, we investigate the use of network simulation tools in teaching computer network. Network simulation tools provide students with the opportunity to freely experiment with virtual computer networks and equipment without the expensive costs associated with real networking hardware.
Keywords- Network simulation tools; Computer network; teaching computer network

INTRODUCTION

The study of computer networks can be challenging. Students have to learn ever-changing technical jargon; master and apply concepts covered in textbooks, lectures, and seminars; and achieve these objectives in a fifteen-week period. Many students complain about the length of time allowed to effectively cover material and are frustrated with the way some computer network textbooks are written. When given the opportunity, lab work provides the students with much needed time to absorb the material and learn how to implement it in the real world. However, it is costly to develop a computer laboratory. Simulation tools can be used to enhance students' understanding and replace some aspects of lab. There are many different network simulation tools such as COMNET III, OPNET, CNET, and Prophesy. When determining which tool to use for computer network lab, we focused on several necessary attributes; inexpensive, user friendly, performance, and meshes well with our coursework. OPNET of Mil 3, Inc. provides a comprehensive development environment supporting the modelling and performing evaluation of communication networks and distributed systems. It provides extensive support for developing models of new components with programming language called Proto-C. The best feature that OPNET offers is the flexibility to develop detailed custom models since it comes with all its Proto-C code. This tool allows the user to simulate practically any system involving requests, services, and queues[1]. However, OPNET simulation package is not easy to learn in one semester and we feel that it is more appropriate for graduate courses. There are high performance tools, such as NetMaker XA from Make Systems, Inc. and Optimal Performance from Optimal Networks. Both tools designed to simulate router, bridge, protocol, and application behaviour. However, they differ from most traditional simulation software. Traditional simulation networks require the user to manually enter and update network data. NetMaker XA and Optimal Performance use actual network protocol information retrieved by probes to automatically interpret and design the network. As an added feature, Optimal Performance issues specific recommendations for improving network performance. However, the expense related to software of this calibre is expensive for universities who aspire to incorporate network simulation tools into their coursework.[6] Optimal Performance comes in two versions, Network and Enterprise. Although these tools are highly accurate and offer many key features, for our purposes neither tool presented itself as a cost-effective educational network simulation

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tool. Our coursework does not necessitate a need for the probes that both applications boast contribute to their amazing accuracy in the collection of data. Many of our labs are centred on teaching the student how to build their own network using data they collect and construct themselves. Secondly, Optimal Performance's ability to recommend network improvements was another feature to Clashed with our educational aims in this course. The exercises are structured to test the student's understanding of performance issues within a network; therefore, Optimal Performance did not meet our needs as an educational tool. The labs and exercises are structured with the intent of getting students to analyze and evaluate network performance and, therefore, to decide for themselves what methods are best to improve networks. Furthermore, we preferred a less expensive application to use for our labs. CNET is a network simulation tool that allows experimentation with various OSI/ISO Networking Reference Model layers, such as the data-link, network, and transport layers. Developed by Dr. Chris McDonald, a professor at the University of Western Australia, CNET is supported by many UNIX and UNIX variants; however, a Windows-based version is still under development. CNET supports a model of networking in which nodes representing either workstations or routers are connected by point-to-point links not by shared physical media, such as buses or rings . It requires network protocols to be written in either the K&R or ANSI-C programming language and supports their execution within a single UNIX process. Although CNET fostered many of the attributes we were looking for, the complexity associated with a command line interface when compared to a GUI interface led us to consider future work with this tool; but our current work compelled us to search for a simpler program. COMNET III provides an integrated, graphical environment for modelling and performance analysis of computer networks. It allows the user to interact with the model during execution. Students are able to graphically display traffic modelling patterns, use realistic network objects to reflect real networks, and apply the concepts discussed in lecture. COMNET III contains a standard Windows ™ interface for building network models. Its GUI interface includes a palette that comprises all of the objects used for manufacturing network models, a standard menu format from which you may activate pull down menus that encompasses most of the windowed applications. Its menus are fairly simple to navigate through, and COMNET III includes a complete and thorough reference manual as well as online technical support.

COMNET III

COMNET III provides detailed modelling of network object logic. An object's I/O subsystems, databases, and the applications that run on the systems can be simulated using this tool. Through the usage of the user's description of the network, its routing algorithms, and workload, COMNET III simulates the operation of the network and provides measurements of network and modular performance. COMNET III was developed using the programming language MODSIM II with an object-oriented design. It was designed with several objects whose characteristics could be modified to match those of real network objects. With COMNET III you can create a variety of network architectures, including LANs, WANs, packet switching, ATM, frame relay, and so on. Moreover, you can define different network topology, such as Ethernet, Token Ring, and Token Bus [9]. Transport layer protocols such as connection-oriented and connectionless-oriented protocols can be selected. The user can segregate reports by object or layer and can select the reports need to be examined. In an effort to provide accurate and realistic simulation results, COMNET III uses discrete event simulation methodology[6]. Analytical methods that develop mathematical based model cannot handle the effects of random variance. Moreover, the model should be approximated to fit the mathematical derivation. Such ability is paramount for the usage of the generated routing algorithms and tables used to model traffic on the network and between objects.

Uses of Network Simulators

Network simulators serve a variety of needs compared to the cost and time involved in setting up an entire test bed containing multiple

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networked computers, routers and data links, network simulators are relatively fast and inexpensive .They allow engineers and researchers to test scenarios that might be particularly difficult or expensive to emulate using a real hardware. For instance, simulating a scenario with several nodes or experimenting with anew protocol in the network. Network simulators are particularly useful in allowing researchers to test new networking protocols or changes o existing protocols in a controlled and reproducible environment. A typical network simulator encompasses a wide range of networking technologies and can help the user to build complex networks from basic building blocks such as a variety of nodes and links. With the help of simulators, one can design hierarchical networks using various types of nodes like computer, hubs, bridges, routers, switches, links, and mobile unit's e.t.c

Various types of wide Area Network (WAN) technology like TCP, ATM, IP e.t.c and local area network (LAN) technologies like Ethernet, token ring e.t.c can all be simulated with a typical simulator and the user can test, analyse various standard results apart from devising some novel protocol or strategy for routing .e.t.c Network simulators are also widely used to simulate battlefield networks in network – centric warfare.

There are a wide variety of network simulators, ranging from the very simple to the complex[10]. Minimally, a network topology, specifying the nodes on the network, the links between those nodes and the traffic between the nodes. More complicated systems may allow the user to specify everything about the protocols used to handle traffic in a network .Graphical applications allow users to easily visualize the workings the workings of their simulated environment .Text –based applications may provide a less intuitive interface, but may permit more advanced forms of customization.

Examples of Network Simulators;

There are many both free/open –source and proprietary network simulators .Examples of notable network simulation software are, ordered after they are mentioned in research papers

(i) Ns (open source)
(ii) OPNET.(proprietary software)
(iii)Netsim.(proprietary software)

Open-Source Network Simulators

This is a list of open-source network simulators and network emulators that run on Linux or BSD.

Cloonix

The Cloonix network simulator provides a relatively easy-to-use graphical user interface. Cloonix recommends KVM to create virtual machines but it also supports other virtualization technologies such as LXC. Cloonix provides a wide variety of pre-built filesystems that can be used as virtual machines and provides simple instructions for creating other virtual machine root filesystems. Cloonix has an active development team, who update the tool every two or three months and who are very responsive to user input.

CORE

The Common Open Research Emulator (CORE) provides a GUI interface and uses the Network Namespaces functionality in Linux Containers (LXC) as a virtualization technology. This allows CORE to start up a large number of virtual machines quickly. CORE supports the simulation of fixed and mobile networks.

CORE will run on Linux and on FreeBSD. CORE is a fork of the IMUNES network simulator, and it adds some new functionality compared to IMUNES.

GNS3

GNS3 is a graphical network simulator focused mostly on supporting Cisco and Juniper software. GNS3 has a large user base, made up mostly of people studying for Cisco exams, and there is a lot of information freely available on

the web about using GNS3 to simulate Cisco equipment.

GNS3 can also be used to simulate a network composed exclusively of Virtual Box and/or Qemu virtual machines running open-source software. GNS3 provides a variety of prepared open-source virtual appliances, and users can create their own.

IMUNES

A team of researchers at the University of Zagreb developed the Integrated Multi-protocol Network Emulator/Simulator (IMUNES) for use as a network research tool. IMUNES runs on the FreeBSD operating system and uses the kernel-level network stack virtualization technology provided by FreeBSD.

IMUNES supports a graphical user interface. It appears to work well and offers good performance, even when running IMUNES on a FreeBSD system running in a Virtual Box virtual machine.

Mininet

Mininet is designed to support research in Software Defined Networking technologies. It uses Linux network namespaces as its virtualization technology to create virtual nodes. The web site indicates that the tool can support thousands of virtual nodes on a single operating system. Mininet is most useful to researchers who are building SDN controllers and need a tool to verify the behavior and performance of SDN controllers. Knowledge of the Python scripting language is very useful when using Mininet. The Mininet project provides excellent documentation and, judging from the activity on the Mininet mailing list, the project is actively used by a large community of researchers.

Netkit

Netkit is a command-line based simulation tool that uses user-mode Linux to create the virtual machines. A full Linux OS can run on each machine. It has good documentation and the project's web site has a long list of interesting lab scenarios to practice, with documentation for each scenario. It also appears to be actively supported by a small community and was last updated in 2011.

Psimulator2

Psimulator2 is a basic graphical network simulator that may be used to demonstrate basic IP networking concepts to students. It is not a fully-functional simulator because only a small sub-set of normal networking functionality is supported on each emulated node. It will run on any system that supports Java; including Windows, Mac OS, and Linux. It offers the ability to "capture" and "play back" data traffic generated by the simulation. The packets are displayed on the GUI as envelopes that move through the network.

Virtual square

Virtualsquare is an interesting effort to create a virtual network tool. The developers are building their own tools to create virtual networks, instead of re-using tools available in the common Linux distributions. There are no prepared labs available so users will have to learn the tool before creating lab scenarios for themselves. The project is well documented. It looks like a research project and Linux kernel or programming skills may be required to fully appreciate it. Virtualsquare is also the source of the Virtual Distributed Ethernet (VDE) program. VDE is used in some of the other network simulation tools.

OPNET:

As networking systems have become more complex and expensive, hands-on experiments based on networking simulation have become essential for teaching the key computer networking topics to students. The simulation approach is the most cost effective and highly useful because it provides a virtual environment for an assortment of desirable features such as modelling a network based on specific criteria and analyzing its performance

under different scenarios with no cost. Different priorities and obstacles do not allow a small college to offer a variety of networks to its students and faculty for using them in the classrooms. As an option, they can use an invaluable tool, the OPNET™ IT Guru Academic software package that offers all the tools for network model design, simulation and analysis at a reasonable cost. OPNET software can simulate a wide variety of different networks, which are linked to each other. The student can just work from his/her PC to simulate different networks and study visually the impact of various factors (e.g., traffic load, bandwidth, data rate, etc.) on the network. With OPNET™ IT Guru, a sophisticated tool that provides analysis and modelling of network performance, users can study data message Flows, packet losses, link failures, bits errors, etc. OPNET software is very user-friendly and easy to install. The IT Guru's installation is straightforward and takes less than 15 minutes. The package has helpful Documentation that is well laid out, easy to use, and includes a large number of examples and tutorials. In addition, the product is feature-rich and contains a steep learning curve. A network technician could find the product very useful in evaluating the effects of new applications and network changes without harming the production network. The laboratory exercise of this paper has been implemented by the students through the use of OPNET simulation Program in there data communication and computer networking course at technical college of Mosul. The students need little knowledge about Queuing theory , line displine how the Discrete Event Simulation works ,some basic traffic models and statistical approaches where these subjects are there syllabus course), after install the OPNET software .The Students then work under supervision in small groups (three or four students). For each LAB exercise, the students implement the Labs analysis results with their teachers, and report writing of the lab experiment in their Group , this both help us and them to assess the efficacy of the simulation experiments in enhancing student learning, through several questions to test the students' understanding of relevant basic concepts From the students' lab feedback, we found that the OPNET Labs benefit students in deep understanding of complicated details of actual systems, encourage active learning (group of students after ending the semester, be able to design a huge computer network for technical college and evaluate the performance of their design.

The purpose of using OPNET

OPNET is the best network simulator to meet teaching
Goals for the following reasons:

- OPNET is much easier to use. It provides a Very convenient Graphic User Interface (GUI) and is very easy to learn.
- OPNET provide quality of documentation *[5]*
- OPNET meets all the needs for use in a different Data communications course *[2]*.
- OPNET is also suitable for use in research OPNET can be used to model the entire network, including its routers, switches, protocols, servers, and the individual applications they support. A large range of communication systems from a single LAN to global inter-networks can be supported [1].
- OPNET software (with model source code) is available for FREE to the academic research and teaching community. Students can download and install OPNET IT Guru Academic Edition at home.
- The OPNET's discrete event engine for network simulations is the fastest and most scalable commercially available solution. It usually takes
  just a few minutes to complete simulations of Most lab experiments
  OPNET has a large user community. OPNET software is used by major fortune-500

Knowledge needed from student to be able to design and simulate a communication network
There are some basic communication building blocks that the students must understand before

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they are able to design and simulate a communication network. A basic understanding of queuing theory is required of students because it plays an important role in the design of computer communication networks and systems.

OPNET overview

OPNET's IT Guru provides a Virtual Network Environment that models the behaviour of an entire network, including its routers, switches, protocols, servers, and individual applications. By working in the
Virtual Network Environment, IT managers, network and system planners, and operations staffs are empowered to diagnose difficult problems more effectively, validate changes before they are implemented, and plan for future scenarios including growth and failure *[3]*.
OPNET is a discrete network simulator which contains a comprehensive development environment supporting the modeling and performance evaluation of communication networks and distributed systems *[6]*.

NetSim

NetSim is a popular network simulation tool used for network design, planning. Various technologies such as Wireless Sensor Networks, Wireless LAN, Wi Max, TCP, IP, etc. are covered in NetSim.

Applications of Netsim

NetSim is widely used for network design validation in

- Network R & D including custom protocol development
- Defence applications
- Railway communication networks
- Airplane sensor networks and in flight entertainment systems

Custom code development

NetSim comes with an in-built development environment, which serves as the interface between User's code and NetSim's protocol libraries and simulation kernel. Protocol libraries are available as open C code for user modification. De-bugging custom code during simulation is an advanced feature: i.e. a simulation can be started and then at user determined breakpoints in the code, users can perform single-step, step-in, step over etc. This can be carried out at various levels (depending on where the user code links) including at a per-packet interval.[5]

Modeling and simulation services

Using NetSim modeling & simulation services are provided in a variety of networking technologies and protocols including MANET, Wi-Fi, Wi-Max, IP, MPLS, WSN, QoS, VoIP etc. This can help avoid the time consuming process of programming, customization and configuration commercial simulators to meet customer specific needs.

Summary table for network simulation tools

Name of Simulator	Open Source	Proprietary	User Interface	Ability to run on Linux and on free BSD	Other Features
Cloonix	✓	-	Easy to use	✓	Regular update by team ,team responsive to user input
core	✓	-	Easy to ues	✓	Adds new functionality as compared to Immunes simulator
GNS3	✓	-	Large user base	✓	Supports Cisco and Juniper software
Opnet	-	✓	Much easier to use	-	Meets all needs for use in a differed data communication course
Netsim	✓	-	Not easy to	-	Used for network design validation in network R& D

			use		including protocol development, defense application etc.
immunes	✓	-	Easy to use	✓	Uses kernel-level network stack virtualization technology
mininet	✓	-	Not easy to use	✓	Supports research in software defined networking technologies
netkit	✓	--	Not easy to use	✓	Has good documentation and the protects website has a long list of interesting lab scenarios to practice with documentation for each scenario
Psimulator2	✓	-	Easy to use	✓	It offers the ability to capture and play back data traffic generated by the simulation
Virtualsquare	✓	-	Not easy to use	✓	Virtualsquare is the source of virtual distributed Ethernet (VDE)

Conclusions

Simulation offers significant advantages as a basis for academic projects in computer networking. Because many unimportant details can be abstracted away, and also because simulations can be completely repeatable, it is possible to address the same concepts more quickly than is possible with actual networks. An important complement to classroom lectures is laboratory experiments. In networking, this often implies programming, protocol design, experiments and measurement. Simulation has an important role here since it allows students to examine problems with much less work and of much larger scope than are possible with experiments on real hardware. Therefore students will come to understand networking theory much better than if they learn only from reading and lectures. This paper shows that using stimulation tools in teaching computer network has provided students with the opportunity to freely experiment with virtual computer networks.
In addition, students gain the knowledge of modelling and simulation technique for performance evaluation of networking systems.

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