CHAPTER 1

INTRODUCTION

1.1 Project Background

The communication has become the very important and necessary component in our daily life to accomplish our tasks. People have to work together cooperatively so that they come out with the solutions for certain problems. To share the information resource among the people who look for solutions must have to be connected to each other to facilitate the communication process. Majority of business organizations nowadays depends on their network communication to achieve their desired business goal. The reliability of the network has become one of the key factors among other success and failure factors of an organization. If the network communication is not reliable, there will be a lot of loss of resources including time and money. UNITEN (Universiti Tenaga Nasional) is one of the organizations among other organizations who rely on the reliability of their network communication to achieve their desired goal. UNITEN has two campuses namely Putrajaya Campus and Muadzam Shah Campus. Those two campuses are located in two different geographic locations and both campuses have their own Intranet [1] operating inside each campus. The two campuses are internet connected via TNB (Tenaga Nasional Berhad) Network which operates by using MPLS (Multi-Protocol Label Switching) Protocol [2]. In this paper, we will discuss about the underlying networking technology, protocols, equipment and performance analysis by simulating the data collected from both actual network users and ITMS UNITEN (IT & Media Service).

1.2 Problem Statement

Campus Intranet of UNITEN has becoming more and more congested in certain period of time and users are not able to browse and utilize the internet connectivity of the campus intranet towards the internet. To answer the questions of "why the network is congested?" and "how to avoid the network congestion?" needs to review the network architecture of the campus and reconsidering the maximum capability of the campus intranet which connect to internet. One of the review and consider methodology is by simulating the campus network with the actual data collected from ITMS and the network users. In the simulation process, the collecting data, modeling or designing and simulating the campus network are involved. The campus intranet will be deploying in the simulator as accurate as possible (devices, underlying technologies, link capacity), the data collected from ITMS and actual network users will be the input to the simulation process, the output will be generated from the simulator and analyze to answer the above two questions.

1.3 Objectives

The objective of this UNITEN Campus Network Simulation project is to know the maximum capacity and network behavior when congested.

- To identify the traffic pattern generated by on campus users (staffs and students)
- To simulate the network based on traffic pattern generated by on campus users (staffs and students)

- To generate report which is composed of maximum capability of the network and network behaviors and user experiences during the time of congestion
- To generate suggestion for optimizing the network to avoid network congestion

1.4 Scope

To collect the actual traffic pattern, the survey called "Universiti Tenaga Nasional Campus Putrajaya Network Utility Analysis" will be conducted to both students and staffs. The data collected from the survey would be the input data which will be using for simulation later on. To get information on actual campus network architecture, an interview will be conducted to ITMS Network Admin. By using the data from ITMS Network Admin, the campus network will be modeled in the simulation project editor interface which includes the device vendor, link capacity, routing protocols and packet propagation across the network. In this simulation project, we will approach the simulation process by using OSI Model [3] (Open System Interconnection Model) approach. We will be discussing and simulating on OSL Layer 1, Layer 3, and Layer 7. The network administrators of UNITEN will benefit from this simulation process since the simulation can realize what is happening in the network and how much traffic and traffic types the network can support for maximum extent. To simulate the campus network effectively, the simulation software called simulator is needed. There are a number of simulators existing in the market which include academic editions, commercial edition and open source. The study and comparison of available network simulators will be done and the simulation process will be conducted by using the most suitable simulator for campus network simulation process.

1.5 Expected Result

The network simulation result with respect to different scenarios and techniques of simulation will be categorized and generalized to ensure how much load network can receive in order to cater the user with optimum performance.

1.6 Project Schedule/ Gantt chart

A Gantt chart represents activities to be done in chronological order to achieve the objectives of this project which is to come up with a simulation process and analysis on current network architecture of UNITEN Putrajaya Campus. The Gantt chart is attached in appendix (Appendix A).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Network Simulation

In this chapter, network design, network models, network simulators, network simulation techniques, the network layer protocols which involve in network simulation process, network topologies which involve in network simulation process, the application layer protocols which involve in network simulation process and the physical link models will be discussed.

2.1.1 Network Simulation

To implement an experimental network in a real time scenario is very difficult because it can consume a lot of resource which include time and money. The network simulators help the network designers and administrators to check whether the network can perform as it is expected to do so in real time or not. To conduct network functionality test by using network simulators can reduce a lot of time and money, and also providing facilities to deploy the networks which are equal or similar to real time scenario [4].

2.1.2 Network Emulation

The author [5] said, the early work of network emulation involved "flake-ways" which are the "gateways" that alter or drop the packets during TCP/IP tests. The recent emulation involves the special purpose and stand-alone network emulators which support packet delays and drops. The recent emulators looks likes the routers to the end station which include PCs, Laptops and mobile phones. Those emulators were developed by developers where they implement the systems as kernel drop-in modules which intercept Network Layer packet forwarding path. Network emulators are limited in capability and the maximum capability of emulator is simple packet manipulation. The simple packet manipulation does not provide interference from simulated cross traffic. The emulators do not support general simulation capabilities which the network simulators do provide.

2.1.3 Network Modeling

According to the author [6], modeling is the process to produce model which is the representation of real system of interest. The model has the similarity to the system which the model represents but the model has higher simplicity than the system. The purpose of modeling is to predict the effect of the changes made to the system. A model should have the similarity with the real system as much as possible and even should inherit the salient features of the system. On top of that, the model should not be very complex so that it is easy to study and conduct experiment with it. A good model has reality and simplicity. The complexity of the model will have to increase iteratively during the experiment performing with the model. One of the important issues in modeling is the model validity. To validate the model, the experiment with the same input must be conducted on both model and the real system which the model represents. If the output from the model and the real system are the same, the model is valid.

2.1.4 Network Planning and Designing

The author here said network planning and design is the process which executes iteratively and covering topological design, network synthesis and network realization. The aim of network planning and design is to ensure that new architecture or design meet the requirement of the customers. The traditional network planning methodology includes five layers of planning namely:

- Business planning
- Long-term and medium-term planning
- Short-term planning
- IT asset sourcing
- Operation and maintenances

2.2 Types of Network Simulators

There are different types of network simulators that can be categorized based on their availability, commercial or free, simple or complex.

2.2.1 Commercial and Open Source Simulators

Author [6] discussed that some of the network simulators are commercial and it means that they will not provide source code of their software or the affiliated packages to the general users for free of charge. All users have to pay for the license or the specific module package which they want to use for their specific project requirements. One of the typical example is OPNET which has two different license type namely; commercial and academic license. For the users who want to use OPNET for their commercial projects, they have to pay for the license and for the academic researchers who wants to do their research and development in network area, they will have to register with their institutional email in order to receive the academic license. Commercial simulators have advantages and disadvantages. The advantages is relatively more that the disadvantages such as learning resource availability, the software capability, ease of use, complete and up to date documentations since they are perfectly maintained by group of people who are specialized for software and documents maintenance in that company.

The open source network simulator has also advantages and disadvantages. Disadvantage is relatively more than advantages particularly in documentation. Generally, to do maintenance and documentation for open source software, there are not enough specialized people. This documentation problem can become very serious if there is new version of software comes with many new features and functions, then the users will be very difficult to trace or understand the previous source codes without appropriate documentations. Lack of enough documentation support and lack of version control support can lead to serious matter such as the applicability and life time of the network simulators. Typically, open source network simulators include Network Simulator Version 2 (NS2), Network Simulator Version 3 (NS3) and OMNET++. The detail discussions of mentioned network simulated will be conducting in following sections.

2.2.2 Simplicity and Complexity of Network Simulators

The author [6] said that currently, the great variety of network simulators are available ranging from simple network simulators to very complex network simulators. In general, a minimum function of network simulator include the network simulator should enable users to represent a network topology, defining scenarios, specifying the nodes (including node type and function) on the network, the links between those nodes and the traffic generation capability among those nodes. The more complicated network simulator allows users to specify everything about the protocols used to process network traffic (i.e. Network Layer Protocols). Another aspect of simplicity and complexity of network simulator is graphical user interface (GUI). Network simulators which have GUI enabled, allow users to easily visualize their works in the simulated environment. Some of the simulators may base on text-based user interface which provide lesser visual or intuitive interface. Some of them may be programming- oriented and can provide programming framework that allows users to create an application which generate network traffic in network testing environment.

2.3 Detail Discussion on Commonly Used Network Simulators

In this section, the discussion of OPNET, NS2, NS3 and OMNET++ will be conducted in details since all of them are commonly used for network research and development tasks.

2.3.1 OPNET (Optimized Network Engineering Tool)

2.3.1.1 Overview

The development environment of OPNET simulator is called OPNET Modeler [6]. OPNET Modeler is specialized for network research and development. OPNET Modeler has flexibility that can be used to study communication networks, devices, protocols, and applications. OPNET is the commercial software provider, then OPNET offer relatively more powerful visual or graphical user interface for users. The graphical interface can be used to create network topologies and entities from Application Layer to Physical Layer. Object Oriented Programming technique is used to create the mapping from the graphical design to the implementation of real systems. The Figure 2.1 shows that GUI of OPNET. The users can see all the topology configurations and simulation results which can be presented very intuitively and visually. The simulation parameter such as amount of traffic generated, amount of time for traffic generation or simulation can be adjusted to repeat the simulation for different scenarios by using GUI. OPNET can run on both UNIX and Windows platform.

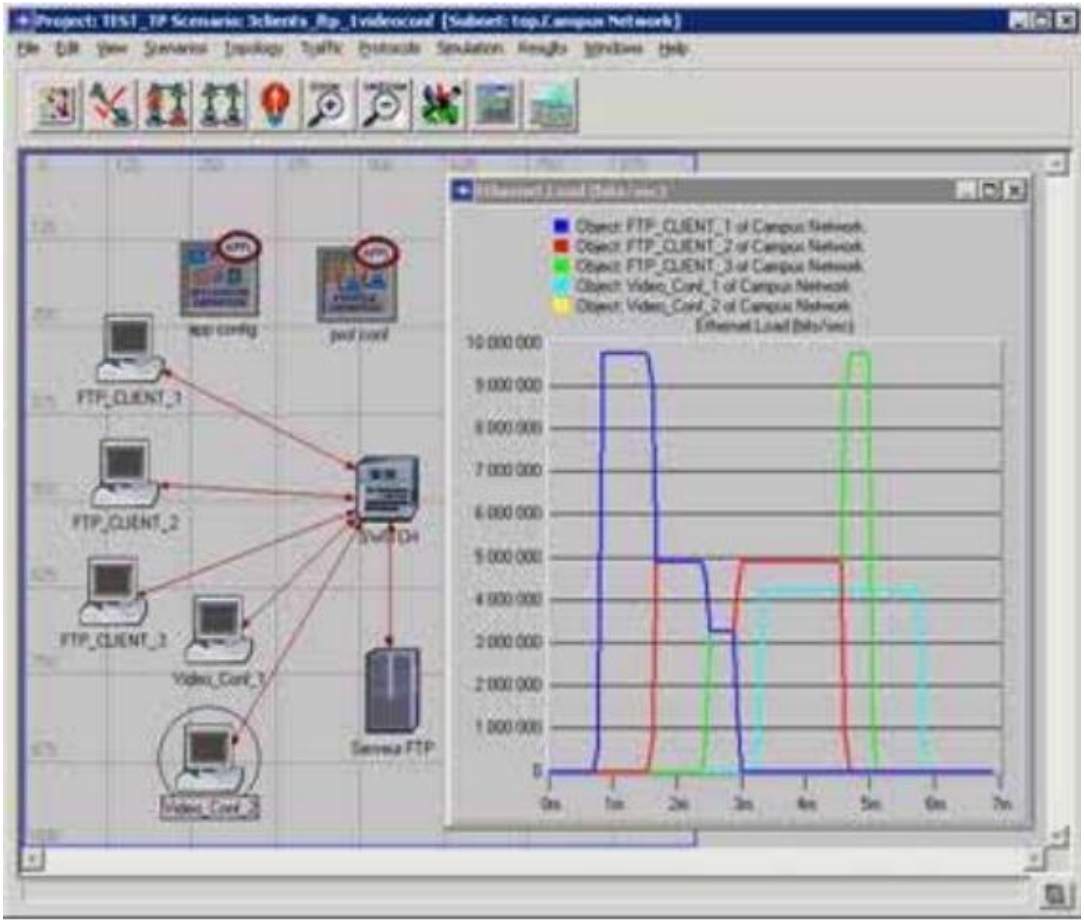


Figure 2.1 OPNET GUI [6]

OPNET system is based on discrete event simulation methodology which means that the behavior of system can be simulated by modeling the events in the system where user has to set the scenarios. Hierarchical structure is used to organize the network which is unique to simulate hierarchical network architectures. The other feature of OPNET is OPNET provide programming tools and interface for users where users can define the packet format and protocols. The programming tools are also required to simulate the networks since the tools provide techniques to define the state of transition machine, network model, and process modules. Figure 2.2 shows the OPNET Process editor Interface and Figure 2.3 shows the OPNET Node Editor Interface.

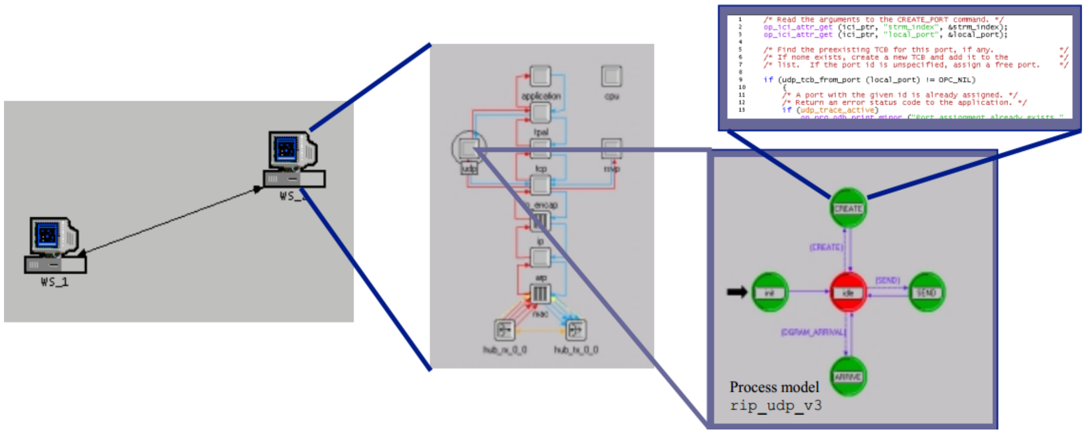


Figure 2.2 OPNET Process Editor Interface [7]

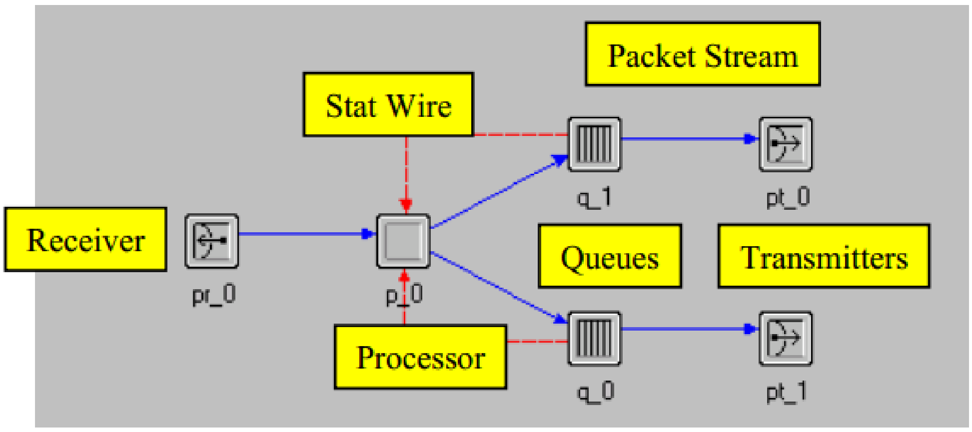


Figure 2.3 OPNET Node Editor Interface [7]

The OPNET is popular simulator used in both industry and academic for network research and development. The GUI interface and Programing tools are very useful to help users to build systems as complex as they want.

2.3.1.2 Main Features

The author [6] said OPNET has three function inherently which are modeling, simulating and analysis. For modeling, it provide graphical user interface which is very intuitive. Users can create all kinds of models of protocols. For simulating, OPNET uses 3 different advanced simulation technologies as said by the author [8]. For analysis, the simulation results and data can be analyzed and displayed using the graphs and also generated web report. User friendly graphs, charts, statistics, and even animations can be generated by OPNET analysis module for convenience of users.

According to OPNET whitepaper, OPNET's detailed features include [6];

- Fast discrete even simulation engine
- Lot of component library with source code
- Object oriented modeling
- Hierarchical modeling environment
- Scalable wireless simulation support
- 32bit and 64bit software architecture of graphical user interface
- Customizable wireless modeling
- Discrete event, Hybrid, and analytical simulation
- Grid computing support
- Integrated GUI based debugging and analysis
- Open interface for integrating external component libraries

2.3.2 Network Simulator 2 (NS2)

2.3.2.1 Overview

The author [6] discussed that NS2 is one of the most popular open source network simulators. The original NS was discrete event network simulator targeted for network research and development. NS2 is second version of NS (Network Simulator). NS was based on REAL network simulator [9]. The first version was developed in 1989. The current NS project is supported DARPA [9]. The current second version (NS2) is widely used in academic research and has a lot of packages contributed by non-profit organizations and groups. NS2 can run on UNIX platform.

2.3.2.2 Main Features

Author [9] discussed that NS2 is an objected oriented, discrete event driven network simulator and was originally developed by University of California-Berkeley. The programming used by NS2 is C++ and OTcl (Tcl scripting language with object-oriented extensions developed at MIT). The biggest reason to use these two programming languages is due to the internal characteristics and features of these two programming languages. C++ is efficient to implement a design but it is not very easy to be visualized and represented graphically. It is not easy to modify and assemble different components and to change different parameters without very visual and easy to use descriptive languages. On top of that, for efficiency reason, NS2 implemented control path and data path separately. The event scheduler and basic network component objects which has been written and compiled using C++ to reduce packet and event processing time. The event scheduler and basic network components object reside in data path. OTcl has the feature that C++ lack to have. Therefore, the combinations of these two programming languages prove to be very effective and efficient. C++ is used to implement detailed protocols and OTcl used to implement for users to control simulation scenario and schedule the events. Figure 2.4 shows the simplified user view of NS2. To initiate the event scheduler, set up topology, and tell packet traffic source when to start and stop sending packet according to event scheduler, OTcl script is used. The scenario can be changed easily by programming the OTcl script. If the user wants to create the new network object, the user can either write the new object or assemble a compound object from the existing object library, and plug the data path through the object. The plugging makes NS2 very powerful. NS is developed in collaboration between DARPA [10], CONSER, ICIR, Sun Microsystems, UCB and Carnegie Mellon Monarch Projects.

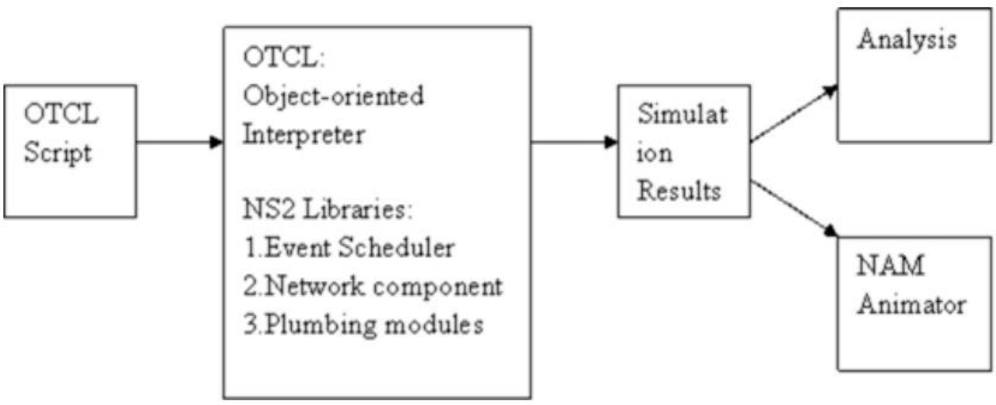


Figure 2.4 Simplified User View of NS2 [11]

2.3.3 Network Simulator 3 (NS3)

2.3.3.1 Overview

Author here [6] discussed that NS3 is also open source discrete event network simulator targeting primarily for research and educational use. NS3 is licensed under

GNU GPLv2 license and is available for research and development. NS3 is designed to replace the current NS2. NS3 is not an updated version of NS2, which means that NS3 is a new network simulator and not backward-compatible with NS2. NS3 can run on UNIX platform.

2.3.3.2 Main Features

Author [6] informed that the basic idea of NS3 comes from several different network simulators such as NS2, YANS [12], GTNetS [13]. The major differences underlying between NS2 and NS3 are;

- Different software core: The core of NS3 is written in C++ and with Python Scripting interface while NS2 was written in OTcl. Several advanced C++ design patterns are also used in NS3
- Attention to realism: protocol entities are designed to be closer to real computers
- Software Integration: NS3 support integration of more open-source software and reduce the needs to rewrite models for simulation
- Support for virtualization: lightweight virtual machines are used for virtualization. Figure 2.5 shows the virtualization testbed of NS3.
- Tracing architecture: NS3 is developing a tracing and statistics gathering framework trying to enable customization of the output without rewriting or rebuilding the simulation core.

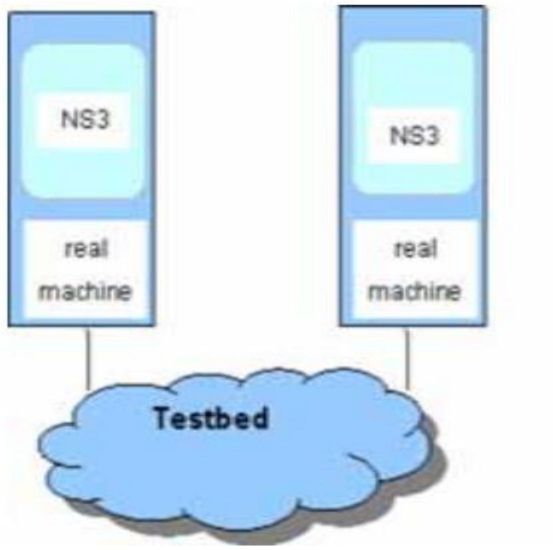


Figure 2.5 Testbeds interconnect NS3 Stacks [11]

2.3.4 OMNeT++

2.3.4.1 Overview

OMNeT++ has similarity with NS2 and NS3 such as public-source, component-based network simulator with GUI support. The primary application area of OMNeT++ is communication networks. OMNeT++ has flexible and generic architecture and it has been successful simulator in other area like IT Systems, queuing networks, hardware architectures and even business processes as well. OMNeT++ is also a discrete event simulator and it is component-based architecture. The components are also called modules and are programmed in C++ [14]. The modules are programmed by using C++ programming language. The modules are assembled into larger models by using high level programming language. The higher level programming language function is similar to the function of OTcl in NS2 and Python in NS3 [14]. GUI is supported by OMNeT++ as well. The simulation kernel can be embedded into all kinds of different user's applications because of its modular architecture. OMNET++ can run on both UNIX and Windows platform. Figure 2.6 shows OMNeT++ GUI.

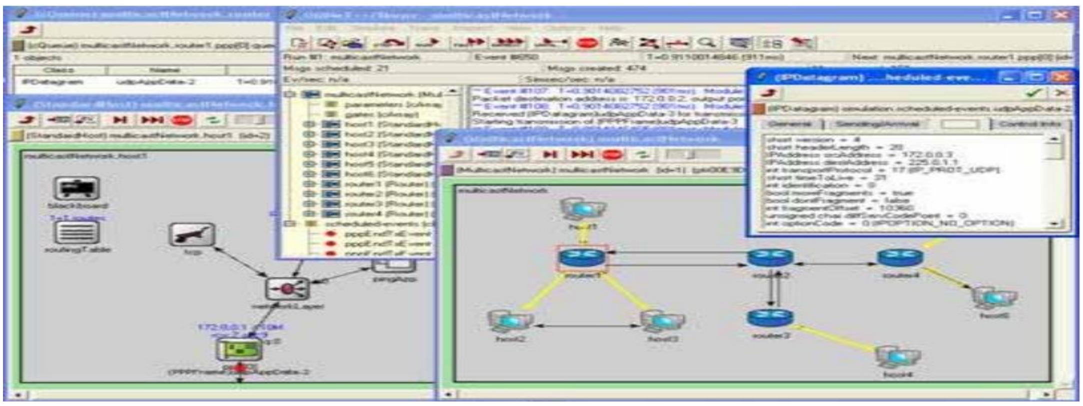


Figure 2.6 OMNeT++ GUI [11]

2.3.4.2 Main Features

Author [14] discussed that modules or models of OMNeT++ are assembled from reusable components since the architecture of OMNeT++ is component-based architecture. One of the main feature of OMNeT++ include that the modules are reusable and can be combined in various ways. The component of OMNeT++ include:

- Simulation kernel library
- Compiler for NED topology description language (nedc)
- Graphical Network Editor for NED files (GNED)
- GUI for simulation execution, links to simulation executable (Tkenv)
- Command line user interface for simulation execution (Cmdenv)
- Graphical output vector plotting tool (Plove)
- Graphical output scalars visualization tool (Scalars)
- Model documentation tool (opp_neddoc)
- Utilities such as random number seed generation tool and make file creation tool, etc.)
- Documentation, sample simulation, etc.

2.4 Comparison among NS2, NS3, OPNET, OMNeT++

2.4.1 Comparison of Advantages and Limitations in NS2

The author of [15] has discussed the advantages and limitations of NS2 as Table 2.1

Table 2.1 Comparison of NS2 Advantages and Limitations [15]

Advantages of NS2	Limitations of NS2
1. NS2 has larger number of available models, realistic mobility models, powerful and flexible scripting and simulation setup, large user community and ongoing development.	1. NS2 needs to be recompilation every time if there is a change in the user code.
2. NS2 provides an easy traffic and movement pattern by including an efficient energy model.	2. Real system is too complex and it is complicated infrastructure to model.
3. NS2 provides a set of randomized mobility model and there are several projects to bring advanced mobility models to simulators.	3. The mixture of compilation and interpretation made it difficult to analyse and to understand the code.
4. Complex scenarios can be easily tested by using NS2.	4. Including a lot of nodes in NS2 may slow down the simulation process.
5. NS2 is popular for its modularity.	

2.4.2 Comparison of Advantages and Limitations in NS3

The author of [15] has discussed about advantages and limitations of NS3 as Table 2.2

Table 2.2 Comparison of NS3 Advantages and Limitations [15]

Advantages of NS3	Limitations of NS3
1. NS3 has high modularity than its ancestor NS2.	1. NS3 still suffers from lack of credibility.
2. NS3 support simulation for TCP, UDP, ICMP, IPv4, multicast routing, P2P and CSMA protocols.	2. NS3 is intended to replicate the successful mode of NS2 in which a lot of different organizations contributed to the models and components based on the framework of NS2.
3. NS3 support for ported code which should make model validation easier and more credible.	3. NS3 needs a lot of specialized maintainers in order to avail the merits of NS3 as the commercial OPNET network simulator.
4. NS3 is much more flexible than NS2.	4. NS3 requires active maintainers to respond to the user questions and bug reports, to help test and validate the system

5. Wide range of use in both optimization and expansion of the existing networks.	

2.4.3 Comparison of Advantages and Limitations in OPNET

The author of [15] has discussed the advantages and limitations of OPNET as Table 2.3

Table 2.3 Comparison of OPNET Advantages and Limitations [15]

Advantages of OPNET	Limitations of OPNET
1. OPNET leverage three different simulation technologies to efficiently trade off simulations detail and speed	1. Complex GUI operation
2. OPNET has fast discrete event simulation engine.	2. OPNET does not allow much number of nodes within a single connected device.
3. OPNET has customizable wireless modelling.	3. OPET result accuracy is by the sampling resolution.
4. OPNET has integrated GUI based debugging and analysis	4. OPNET simulation is inefficient if nothing happens for long periods.

2.4.4 Comparison of Advantages and Limitations in OMNeT++

The author of [15] has discussed the advantages and limitations of OMNeT++ as Table 2.4

Table 2.4 Comparison of OMNeT++ Advantages and Limitations [15]

Advantages of OMNeT++	Limitations of OMNeT++
1. OMNeT++ provide a powerful GUI environment	1. OMNeT++ does not offer a great variety of protocols and very few protocols have been implemented, leaving users with significant background work.
2. OMNeT++ has tracing and debugging module which are much easier than other simulators.	2. OMNeT++ has poor analysis and management of typical performance.
3. OMNeT++ has the ability to model most hardware accurately and include the modelling of physical phenomena.	3. OMNeT++ mobility extension is relatively incomplete.

2.5 Minimum Hardware and Software Requirement for Network Simulators

The author of [15] suggested the minimum hardware and software requirement for network simulators as Table 2.5

Table 2.5 Minimum hardware and software requirement for network simulators [15]

Network Simulator	Type	Programming Languages	Supported Operating System	Hardware Requirement
1.NS2	Open Source	C++ and Object-Oriented Tool Command Language (OTcL)	GNU/Linux, FreeBSD, Mac OS X, Windows XP, Windows Vista, Windows 7	Free disk space of 5GB required and minimum of 256 MB of RAM suggested
2. NS3	Open Source	C++ and Optional Python Bindings	GNU/Linux, FreeBSD, Mac OS X, Windows XP, Windows Vista, Windows 7	Free disk space of 5GB required and minimum of 256MB

				RAM suggested
3. OPNET	Commercial/ Free Academic License	C and C++	Windows XP, Windows Vista, Windows 7, Windows NT 4.0	Free disk space of 200MB required and minimum of 256 RAM suggested
4. OMNeT++	Free for academic and non-profit use	Full system is developed with C++ but it also support C# and Java in its IDE environment	Windows, Linux, Mac OS X, and other Unix like OS.	Free disk space of 400MB is required and minimum of 512MB RAM is suggested

2.6 Review of Network Simulation Methodologies

2.6.1 Discrete Event Simulation Method

Authors [16] discussed that discrete event simulation is the simulation method which models the operation of real system as discrete sequence of events in time. Each of the events occurs in particular time interval and this event marks a change of system state. Between two consecutive events, there is no changes in the system is assumed. Therefore, the simulation can directly jump from one event to another event. The discrete event simulation is composed of:

- State

  A state of system is a variable set which captures the salient features and properties of the real system of interest. The state trajectory overtime can be represented mathematically by a step function [17]. The values of step function change with respect to discrete events.

- Clock

  Current simulation time must be kept tracked by simulation in any measurement units but they must be suitable for the system being modeled. In discrete event simulation, the time 'hop' since the event is instantaneous. The clock skips to next event start time as the simulation proceeds.

- Event List

  At least one list of simulation events are maintained by simulation process. This is sometimes called pending event set since there are lists of events which are pending to be simulated if the previous simulated event is not yet finished. An event is denoted by the time at which it occurs and type. When the events are instantaneous, the activities that extend over time are modeled as sequences of events. Single threaded simulation engines which are based on instantaneous events have only one current event. Multi-threaded simulation engine and simulation engines which support interval-based event modal may have multiple current events.

- Random number generators

  The simulation process needs to generate various kinds of random variables depending on the system model. To accomplish the random number generation tasks, one or more Pseudorandom number generator [18]. The use of pseudo random numbers are opposite from the use of true random numbers. The benefit is if the simulation needs to re run again, the simulation will run again with the exactly same behavior.

- Statistics

  The simulation keeps tracking of statistics of the system which quantify the aspect of interest.

- Ending Condition

  Theoretically, the discrete event simulation could run forever since the events are bootstrapped. Therefore, the simulation designer has to decide when the simulation should end. The ending condition include “at certain time interval”, after processing certain number of events” or generally “at the time if statistical measurement of x reach the value of x”.

2.6.2 Real time Simulation Method

The author [19] discussed that real time simulation method is a computer model of a physical system which can execute as the same rate as the real clock time, which means that the computer model runs at the same rate of the real physical system. For example if a person will take to finish certain task with 10 minutes, the person object in the simulation process would take 10 minutes to finish the task as well. Real time simulation is dedicated and commonly used for computer gaming. Real time simulators are used extensively in many of the engineering fields of study such as statistical power grid protection tests, aircraft design and simulation, motor drive controller design methods and space robot integration.

2.6.3 Continuous Simulation Method

Authors [20,21,22,23] discussed that continuous simulation methods is a methodology which refers to a computer model of a physical system which track system response continuously according to set of equations. Continuous simulation allows prediction of rocket trajectories, hydrogen bomb dynamics, electric circuit simulation and robotics. Continuous simulations are based on sets of differential equation which defines peculiarity of the state variables, the environment factors to speak, of a system. In the continuous simulation method, the conceptual model must be constructed by using set of differential equations. To develop a conceptual model, there are two approaches namely deductive approach and inductive approach. The deductive approach states that the behavior of system arises from physical laws that can be applied while the inductive approach states that the behavior of the system arises from observed behavior of an actual example.

2.7 Review of UNITEN current Network Architecture

Interview with UNITEN ITMS system analyst yield the information of current network topology, hierarchical network architecture, routing protocols and network applications used by UNITEN [43].

2.7.1 Topology Review

Currently, UNITEN Campus Network Architecture is based on Mesh Network Topology and Start Network Topology. Fully Mesh Network topology is underlying at the core network layer and the Star Network Topology is being implemented in both Distribution and Access Network Layers.

Network Topology can be subdivided into physical network topology and logical network topology [24].

2.7.1.1 Physical Network Topology

The author of [24] states that physical network topology emphasizes the hardware associated with the systems which include, workstations, remote terminals, servers, and associated wiring between assets. Figure 2.7 shows the physical topology of a computer network.

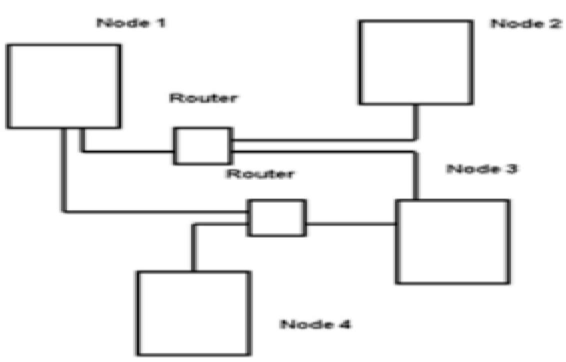


Figure 2.7 Physical Network Topology [24]

2.7.1.2 Physical Star Shape Topology

Author [24] said that start network topology requires the use of central node which is at the top level and to which all other nodes are connected. The top level node may be a computer, a switch, or just a common connection point. Messages received by the top level node (such as Hub) can further be broadcasted to all subordinate nodes or if the top level node (such as switch) is smart enough to send only to the desired subordinate node. Inter node messaging delays are reduced with this configuration. Failure in the connection between top level node and subordinate node or failure in the subordinate node will not disrupt the entire network. This is an important advantage of Star Network Topology. Star Network topology is commonly used in a LAN [25] which span in larger geometric area. One of the disadvantages of Star Network Topology is that it needs more cabling than any other network topologies. Figure 2.8 shows a typical Star Network Topology.

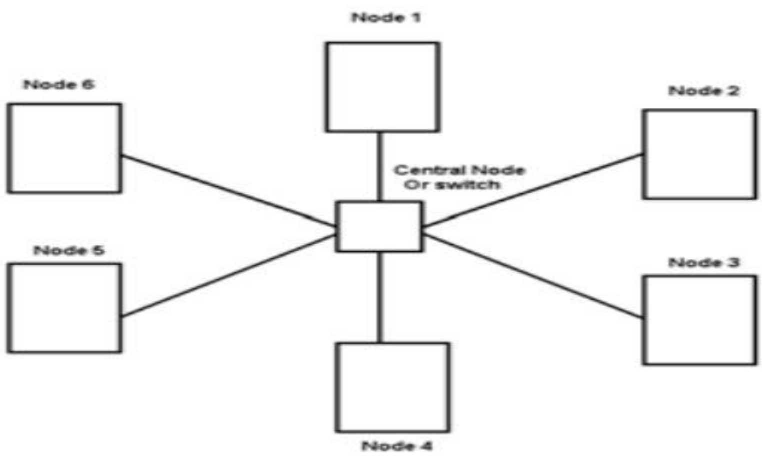


Figure 2.8 Typical Star Network Topology [24]

2.7.1.3 Physical Mesh Network Topology

Author of [24] states that Mesh Network Topologies capitalize on path redundancy. This topology is preferred if the traffic between node is large. Every node in this type of network have multiple to another destination node. The probability of single point network failure is greatly minimized with the Mesh Network Topology. The major advantages of Mesh Network Topology is that source node determine the best route from sender to destination based on connectivity, speed, pending node tasks. A disadvantage of Mesh Network Topology is that it incur large cost when implementation. There are two types of Mesh Network Topology namely Full Mesh and Partial Mesh. In Full Mesh, each node being directly connected to every other node in the network while in Partial Mesh, having some nodes in the network being connected indirectly to the others in the network. Figure 2.9 shows the Full Mesh Network Topology and Figure 2.10 shows the Partial Mesh Network Topology.

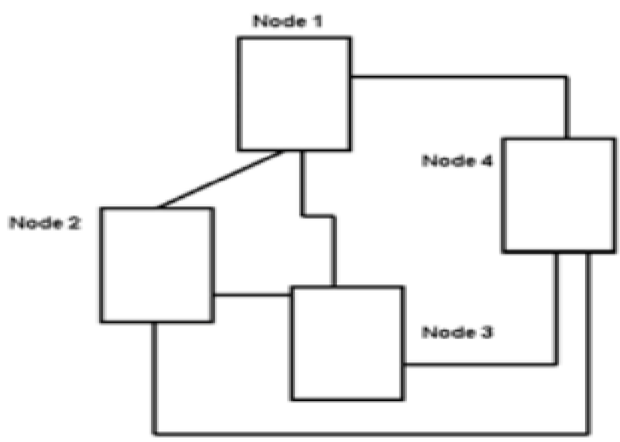


Figure 2.9 Typical Full Mesh Network Topology [24]

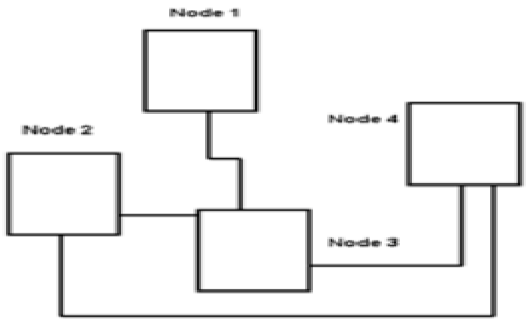


Figure 2.10 Typical Partial Mesh Network Topology [24]

2.7.1.4 Logical Network Topology

The author of [24] states that the logical network topology which is also known as signal topology emphasizes the representation of data flow between nodes. Logical topology of the network can be dynamically reconfigured when selecting network equipment such as router. Figure 2.11 showing logical topology of a computer network.

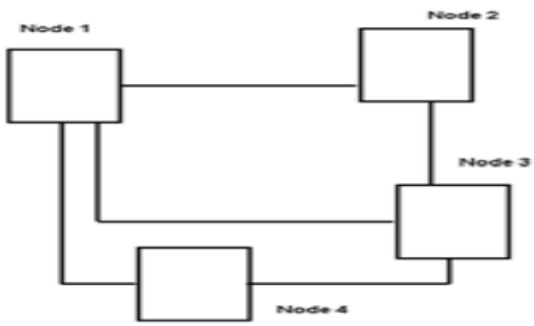


Figure 2.11 Logical Network Topology [24]

2.7.2 Routing Protocol Review

Currently, UNITEN Campus network routing process is based on two routing protocols namely RIP and BGP [43].

2.7.2.1 Routing Information Protocol (RIP)

RIP is also known as Routing Information Protocol. RIP is Network Layer protocol and true discrete vector Protocol. RIP sends out the complete routing table to all active interfaces in every 30 seconds. RIP use hop count as the cost to determine the best route to remote network. This hop count is limited to 15 by default and meaning that the remote located at 16th hop count is not reachable. RIP is only suitable for small networks and if the network is too large, RIP becoming inefficient due to large numbers of router installed in the network. RIP version support only class-full routing, this means that all devices in the network must use same subnet mask. RIP version 1 does not send subnet mask information when it sends the routing table update. In RIP version 2, there is something called prefix routing and hence support classless routing by sending subnet mask information in route updates [26].

2.7.2.2 Border Gateway Protocol (BGP)

BGP is also known as Border Gateway Protocol. BGP is routing protocol which operates at the network layer. BGP is used to exchange network layer reachability information (NLRI) between routing domains. Routing domain is also known as Autonomous System (AS) because different administrative authorities control their own respective domains. The current internet is the network of interconnected routing domains where BGP version 4 is the de facto routing protocol [26].

2.7.3 Underlying Networking Technology Review

Currently, UNITEN Campus networking technology is based on Ethernet Technology [43]. Author of [27] states that Ethernet is the most widely used LAN technology whose specific standard is IEEE 802.3. It was developed by organization called Xerox and the specification was called Aloha net. Ethernet was for Palo Alto Research Centre Aloha Network. It was further developed by Xerox, DEC and Intel. Ethernet LAN typically used coaxial cable or special grades of twisted pair wires. Wireless LAN also uses Ethernet. The most typically installed in Ethernet is 10BASE-T which has the maximum transmission speed up to 10Mbps. The devices which are connected to cable are in shared media. Those devices use Carrier Sense Multiple Access with Collision Detection (CSMA/CD) protocol. 100BASE-T or also known as Fast Ether is typically used for LAN backbone systems. This 100BASE-T provides transmission speed up to 100Mbps. The workstations which has 10BASE-T card also can use 100BASE-T fast Ethernet but the data transmission speed will be maximum of 10Mbps. Ethernet even provide even higher level backbone support at 1000 Mbps.

2.7.4 Network Architecture Review

Currently, the campus network of UNITEN is based on hierarchical network design which consists of Core Layer, Distribution Layer and Access Layer [43].

2.7.4.1 Core Layer

According the author [28], he states that core layer of a network model is crucial for interconnecting between distribution layer devices and outside internet. The redundancy and availability is critical in the core layer. Normally, high performance routers are used as core layer devices since there is network address translation between intranet and outside internet.

2.7.4.2 Distribution Layer

The author of [28] states that Distribution layer aggregate the data received from all devices connected to access layer. After receiving the data from access layer devices, distribution layer switches transmit the data to core network layer. High performance switches are used in distribution since the load of data is relatively bigger than access layer and to make sure the network has redundancy and high availability.

2.7.4.3 Access Layer

The author [28] discussed that Access layer allows end devices to be connected to network via access switch or wireless access point. End user devices include PCs, Laptops. Printers, Mobile phones and Tablets.

2.7.5 Review of Application Layer protocols used in UNITEN

2.7.5.1 File Transfer Protocol (FTP)

FTP is to promote sharing of files, to encourage indirect or implicit use of remote computer programs, to shield user from variations in file storage systems among hosts, and to transfer data reliably and efficiently. FTP is usable via a terminal by the user but is designed mainly for use by programs. One of the FTP applications is FileZilla [29].

2.7.5.2 Hypertext Transfer Protocol (HTTP)

HTTP is known as Hypertext Transfer Protocol. HTTP has three versions which are HTTP 1.0, HTTP 1.1 and HTTP 2.0. HTTP is stateless application layer protocol for distributed, collaborative and hypertext information systems. HTTP is popular in retrieving web related documents [30].

2.7.5.3 Voice over Internet Protocol (VoIP)

Voice over IP (VOIP) uses IP (Internet Protocol) to transmit voice as packet over and IP Network. VOIP can be achieved on any data network which uses IP like, Internet, Intranet, and Local Area Network (LAN). The motivations of internet telephony are very low cost, demand for multimedia communication and demand for integration of voice and data network. Some of the popular protocols in VOIP are H.323, Session Initiation Protocol (SIP) [31].

2.7.5.4 Simple Mail Transfer Protocol (SMTP)

SMTP is also known as Simple Mail Transfer Protocol. SMTP is used for transporting electronic mail among different hosts within department of Defense Internet Protocol Suite. A user SMTP process opens a TCP connection to a server SMTP process on a remote host to send mail via the connection. SMTP process from server listen for TCP connection via well-known port 25 and user SMTP process initiate a connection to that port. If the TCP connection is successfully established between server SMTP process and user SMTP process, simple request and response dialogue/message are executed defined by SMTP Protocol. The message must contain a message header and message text formatted [32].

2.7.5.5 Post Office Protocol version 3 (POP3)

POP3 is also known as Post Office Protocol version 3. POP is one of the methods of accessing email. POP3 is older than IMAP. POP3 does not maintain folder hierarchy in server side so that user may have difficulty to retrieve email if user has to access from different computer rather than usual one [33].

2.7.5.6 Internet Message Access Protocol (IMAP)

IMAP is also known as Internet Message Access Protocol. IMAP is one of the methods of accessing email as well. IMAP provides server-side storage and manipulation of email. IMAP works better than POP3 if user has to access email via multiple computer and also via web. IMAP maintain email folder hierarchy in server side [33].

2.7.6 Review of Transport Layer Protocols used in UNITEN

2.7.6.1 Transmission Control Protocol (TCP)

TCP is Transport Layer Protocol. TCP is connection oriented since TCP implement the mechanism to setup and tear down a full duplex connection between end points. The data sent over network via TCP is guaranteed that the receiver will receive correctly and completely since TCP has mechanism for error free and in order delivery of data. TCP also has flow control and congestion control mechanism which control traffic within transmission links [34].

2.7.6.2 User Datagram Protocol (UDP)

UDP is also Transport Layer Protocol. UDP is connectionless protocol and datagrams are delivered independently. UDP is not reliable in transmission of data since UDP cannot guarantee for data loss, corruption, and duplication and in order delivery [34]

CHAPTER 3

ANALYSIS AND METHODOLOGY

In this chapter, the methodology of network simulation, the survey conducted, the network simulation software, and the interview results will be discussed.

3.1 Survey Analysis

3.1.1 Survey Content

A survey regarding to how network users in UNITEN utilize the internet connection in daily basis has been conducted by using google online survey forms. The survey includes 6 questions and in multiple choice format.

Question 1 asks about the individual is staff or student to differentiate staff network and student network where the source of the traffic where it comes from.

Question 2 asks about where the individual is staying and the point is to know the exact initiation point of the generated traffic.

Question 3 asks about how does the individual utilize the internet connection and the point is to know what kind of traffic they are generating most and least.

Question 4 asks about how much is the average file size an individual download and the point is to know how much bandwidth the individual consume.

Question 5 asks about what time the individual download the file and the point is to know the business of the network during day and night.

Question 6 asks about how often the individual download the file so that we can see the actual business of the network in daily basis.

3.1.2 Analysis on Survey Response

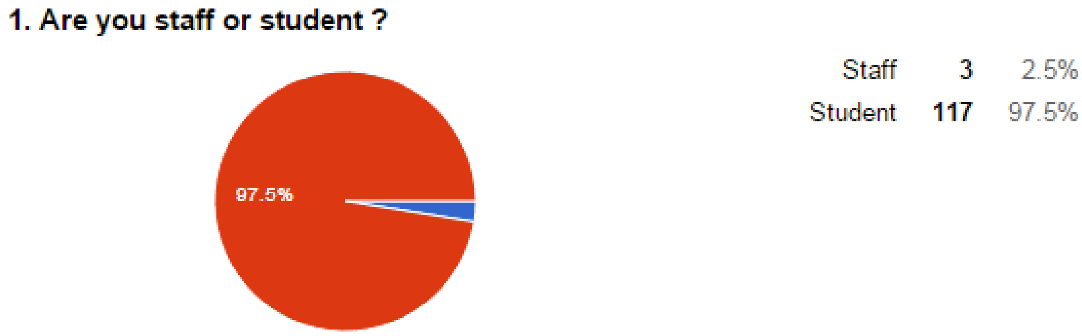


Figure 3.1 Survey Responses for Question 1

Out of 120 individuals who respond the survey, 117 are the students and 3 are the staffs. In percentage, 97.5% of students respond to the survey while the rest are staffs.

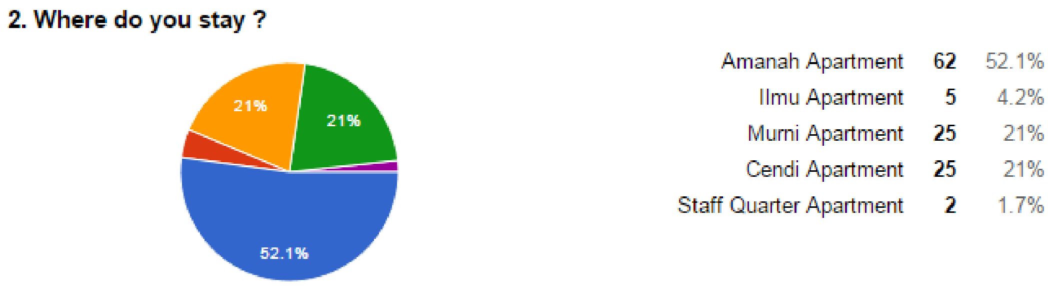


Figure 3.2 Survey Responses for Question 2

Out of 120 individuals who respond to survey, majority of them are from Amanah student apartment. Second majority are from Murni and Cendi student apartments and the rest are from Ilmu student apartment and staff quarter apartment. In percentage, 52% of the Amanah students respond to survey. 21% of Cendi students, 21% of Murni students, 4.2% of Ilmu students and 1.7% of staff quarter residences responded to the survey.

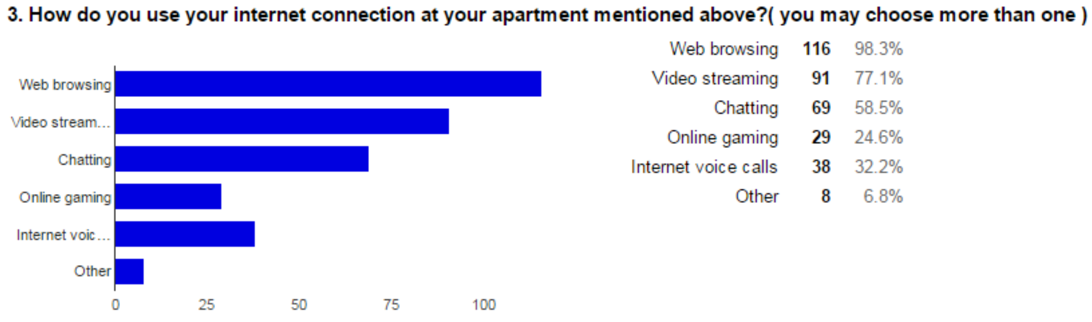


Figure 3.3 Survey Responses for Question 3

The response graph for question number 3 is showing that majority of network users in UNITEN are web explorers. The second majority of network users are video streamers while third majority of the network users are chat application users. The rest of the users are online gamers and VoIP users. There are some individuals who do assignments and group discussions using internet as well.

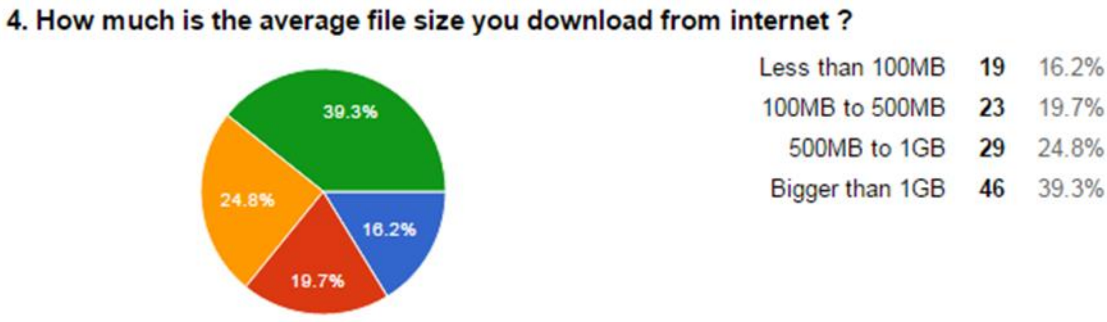


Figure 3.4 Survey Responses for Question 4

The pie chart shows that average file size that the majority of network users download is bigger than 1GB. This is one of the major reasons why the network is busy. The second largest group of the network users downloads average file size bigger than 500MB but smaller than 1GB. Very few numbers of network users download average file size of less than 100MB.

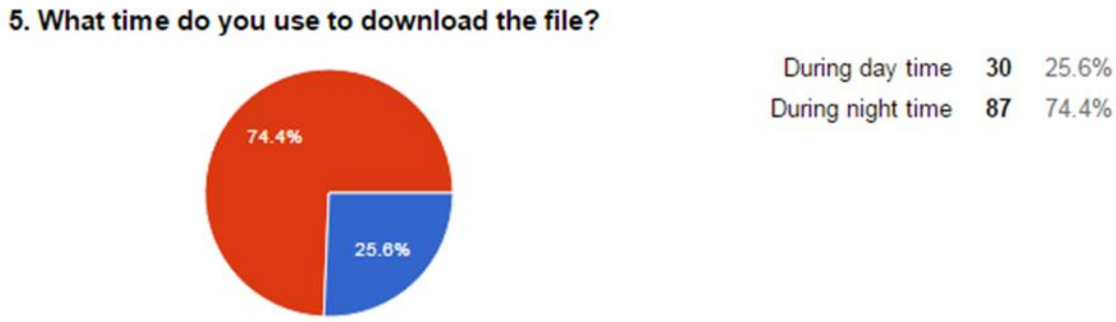


Figure 3.5 Survey Responses for Question 5

The pie chart shows that majority of the users like to download the file during night time. Minority of the users download at day time. It means that network congestion is peak at night time.

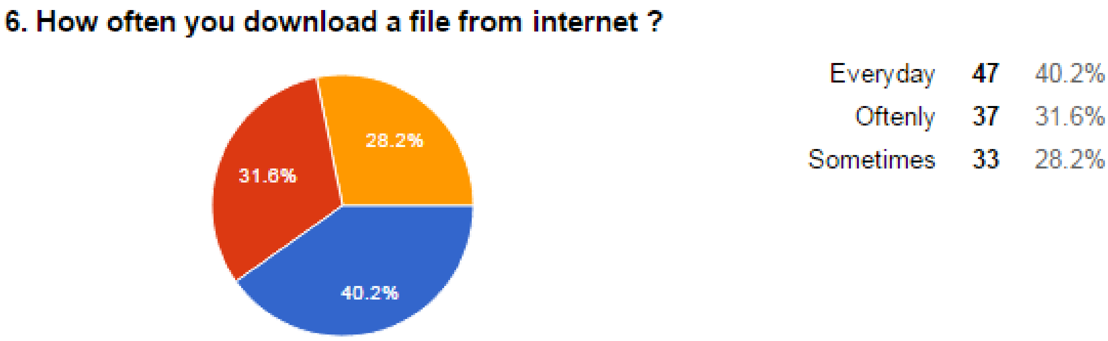


Figure 3.6 Survey Responses for Question 6

The pie chart shows that majority of the network users download file in daily basis while second majority of the users download often and very few minority of the users download sometimes.

3.2 Analysis on Interview session with ITMS System Analyst

An interview has been conducted with Encik Abdul Faizal who is the system analyst from UNITEN Campus Putrajaya ITMS. The interview took place at his office which is located within ITMS building on 30th June 2015. Single session of interview was being conducted and due to some confidentiality, the actual review on UNITEN network was not able to be conducted. During interview, the network architecture, the routing protocols, the packet flow direction and the WAN links capacity were mainly discussed.

3.2.1 Analysis on UNITEN Network Architecture

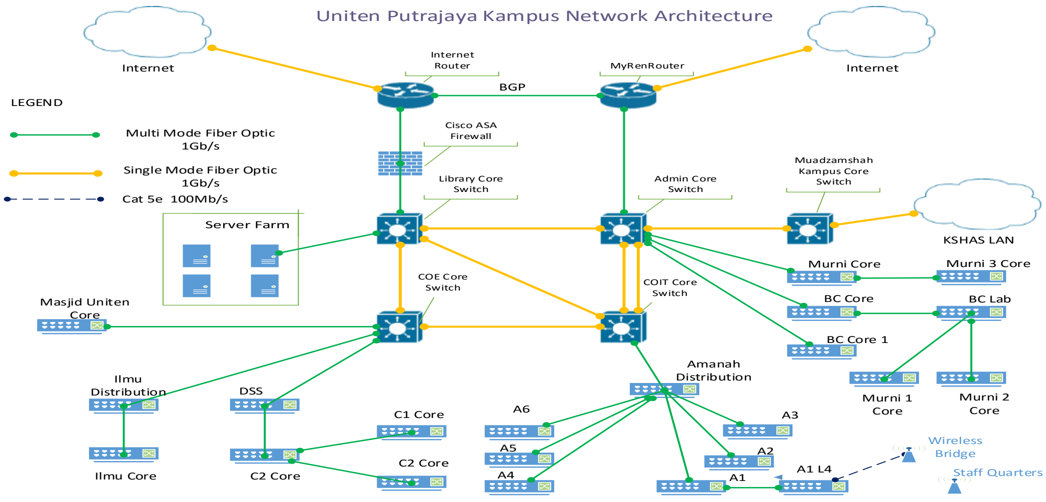


Figure 3.7 UNITEN Putrajaya Campus Network Architecture [43]

3.2.2 Analysis and Discussion on UNITEN Network Architecture

3.2.2.1 Physical Architecture

UNITEN Network is a converged and hierarchical network model which consists of Core Layer, Distribution Layer and Access Layer [43].

3.2.2.1.1 Core Layer

There are 4 core layer switches (Cisco C6509) which locates in Library Block, Administrative Block, College of Computer Science and Information Technology Block and College of Engineering Block. These 4 core switches are connected with Single Mode Fiber Optic Cables since the distance between them is quite far and the Multi-Mode Fiber Optic Cable cannot capable of conveying electrical signals. From Administrative Block core switch, there is MPLS enabled link to Muadzam Shah Kampus Core Switch where communication between 2 different geographic kampus takes place. This MPLS service is from Tenaga Nasional Berhad (TNB).

3.2.2.1.2 Distribution Layer

According to UINTEN (Kampus Putrajaya) Network Architecture, there are 2 Level Core Switches or Sub-Core switches which are Primary Core Switch and Secondary Core Switch. Primary Core switches are the switches really existing in the very core level of the architecture which we have already mentioned above. The secondary core switches are sub-core switches (also known as Distribution Layer Switch in this case) which are existing in the building block (for example, ILMU Hostels Block) for the purpose of distribution of cable connectivity to each building (for example, ILMU 1, ILMU 2, etc..). The connectivity between Core switch & Distribution Switch is via Multi-Mode Fiber Optic Cable. There are switches in each floor of the building namely Access Layer Switch which we are going to explain below.

3.2.2.1.3 Access Layer

In every floor of the building, there is an access layer switch which directly connects to end user device in terms of either wired or wireless technology. However, most of the connectivity in UNITEN is using Ethernet technology with the data rate varying from 100Mbps to 1000Mbps. However, this is link speed only and the actual data rate really depends on many factors like network behavior, congestion of the network inside campus and the processing rate of proxy servers etc. The connectivity between the distribution switch and access switch is via Ethernet technology.

3.2.2.2 Logical Architecture

Logical Architecture shows logical topology saying how the packets or frames are travelling from one point to another point throughout the network. Logical Architecture includes Switching and Routing.

3.2.2.2.1 Switching

Every communication originated and destined towards inside campus, the switches which include (Access Layer, Distribution Layer, and Core Layer) are enough to convey the message to and fro. If the destination address in the IPV4 header is the public address rather than private address, the traffic will hit the Forefront Threat Management Gateway (TMG) proxy server and the proxy server forward the traffic to gateway router which is cisco ASA firewall. Cisco ASA firewall check the traffic according to outbound rule designated by network admin. If the traffic can satisfy the rule, the traffic is allowed to pass through Cisco ASA firewall and hit the Internet Router.

3.2.2.2.2 Routing

Then traffic originated from Cisco ASA firewall will hit the internet router which is also known as gateway router. In this place, where Network Address Translation (NAT) & Port Address translation (PAT) incur. The traffic will propagate into internet through internet router of UNITEN. There are 2 internet routers in UNITEN which are of Cisco 3900 series. Router 1 (also known as Internet Router in the diagram) is capable of forwarding any traffic except the domain name ".edu". Router 2 (also known as MYREN Router in the diagram) is capable forwarding traffic with domain name ".edu".

3.3 Network Simulator Analysis

In this section, the analysis of network simulator software which will be adopted for this project will be discussed.

3.3.1 OPNET for Campus Network Simulation

The OPNET was chosen as Network Simulator for this project since there are a lot of several literature reviews on OPNET to simulate campus network. The authors of [35] performance analysis by using OPNET is at SUNY College at Fredonia, New York. The Project was to satisfy the increasing demands of network resource; the college has to implement the Switch Ethernet Subnets and Gigabit Ethernet Backbone. To implement the VoIP and video conferencing for future development, the researchers from said university used OPNET to estimate and visualize the ability of the network. Their works focused on performance measurement and improvement in network capability by using innovative algorithms and identification of potential bottlenecks in communications. They model the campus network using OPNET. For them, the various features provided by OPNET were very handy such as custom model creation for the elements which are not present in the built in models.

There are many other campus network simulated and analyzed by using OPNET Modeler such as the universities in China [36], the university of Sheffield [37], IPv6 deployment of Zhaoqing university in China [38], the fault tolerant campus area network of universities in Nigeria [39], the campus back bone of university in Belgium [40] and so on.

3.3.2 Protocols supported by OPNET

The OPNET Modeler comprises of protocols and technologies with sophisticated development environment. By modeling all network types and technologies in the modeler, riverbed Modeler analyze networks to compare the impact of different technology design on end-to-end behavior. These technologies include VoIP, TCP, OSPFV3, MPLS, IPV6 and many more. Riverbed Modeler let us test and demonstrate technology designs before it is actually implemented hence enhancing network research & development productivity and evaluate enhancement to standard based protocols [41].

3.3.3 OPNET Features

The features of OPNET provide the ease of use which include [15];

- OPNET has three main functions; modeling, simulating and analysis
- OPNET provide intuitive graphical environment to create all kind of protocol models.
- OPNET consists of high level user interface which is constructed from C and C++ source code blocks with a library of OPNET Specific functions.
- OPNET arrange its hierarchical model into three specific domains: Network domain, Node domain, and Process domain.
- OPNET model network protocols, resources, algorithms, applications and queuing policies in detail using OPNET Modeler's powerful object-oriented modeling approach.

The hardware requirement and the platform support also one of the reasons to choose OPNET as a modeler and simulator for this project. The programming in OPNET modeler can be done using flavor C and C++ language. The hardware requirement is affordable requirement which is 200MB of disk space and 256MB of RAM to run OPNET on Windows based platform.

3.3.4 OPNET for UNITEN Campus Network Simulation

Simulation processes which can be carried out with OPNET for this project include, IPV4, traffic generation based on different types of application, routing protocols, different network technologies including Ethernet, firewall.

3.4 Network Simulation Methodology Analysis

The discrete event simulation methodology will be adopted because discrete event simulation provide the followings features and advantages [42],

- Discrete event simulation is used to enact the system that have a queue network model (delay) as well as to compare and predict the outcome of a particular scenario.
- Discrete event simulation focuses on the process that involves the use of queue.
- Discrete event simulation is mostly used in decision and prediction making.
- Discrete event simulation is used at the operational level and it is top down approach
- ‘Discrete event simulation is easy for user to understand with the help of animations and graphics that build in the OPNET Modeler.
- Having unlimited flexibility to determine the behavior of entities.
- Straighter forward to be modeled once the problem has been clearly defined

CHAPTER 4

DESIGN

4.1 Visualization of OPNET Modeler User Interface

OPNET arrange the model into three specific domain that are Network domain, Node domain and Process domain.

4.1.1 Network Domain Design

Network domain includes Networks and sub networks, network topologies, geographical coordinates and mobility. Figure 4.1 shows Network Level Main Window for Wide Area Network simulation where WAN links are connected from country to country. Network domain specifies the overall scope of the system to be simulated. Network level domain is the high level description of objects contained in the system. Network model specifies the objects in the system as well as their physical location, interconnections and configurations as shown in the Figure 4.1 where network topology has been constructed on World Map. Figure 4.2 shows that each subnet icons on the word map represent groups of network nodes within that subnet.

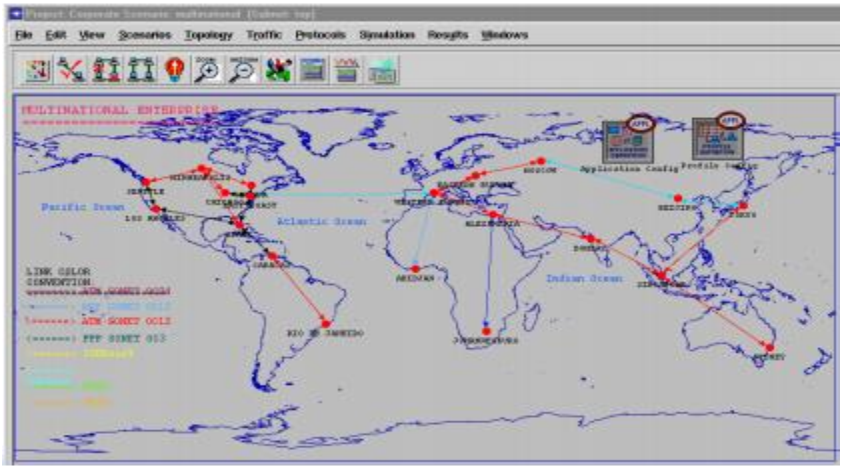


Figure 4.1 Network Level Main Window for Wide Area Network Simulation[15]

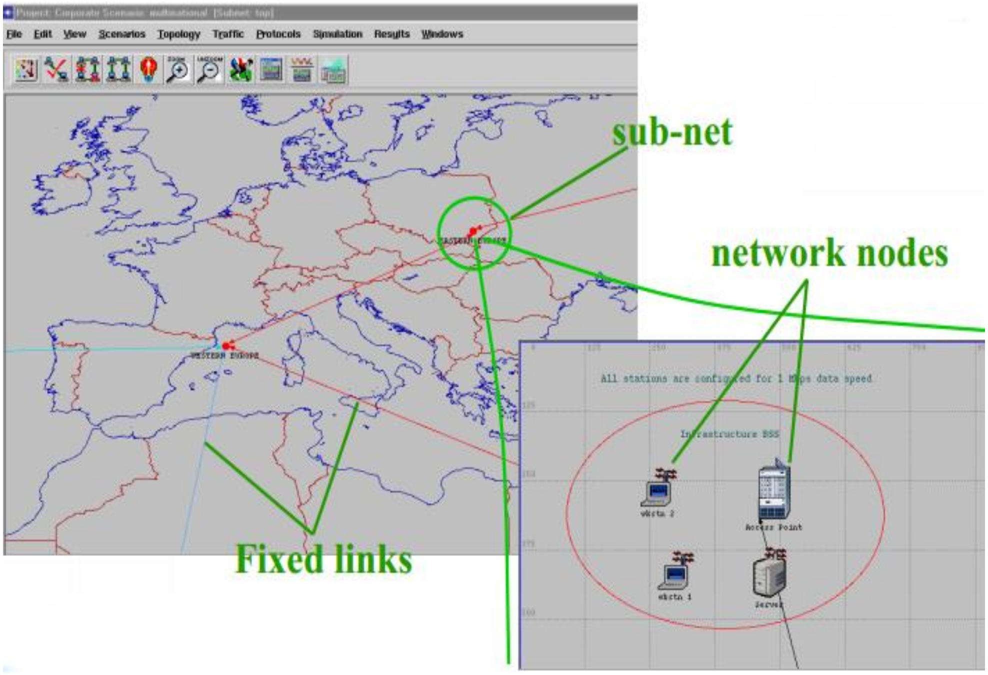


Figure 4.2 Subnet of network nodes [15]

4.1.2 Node Domain Design

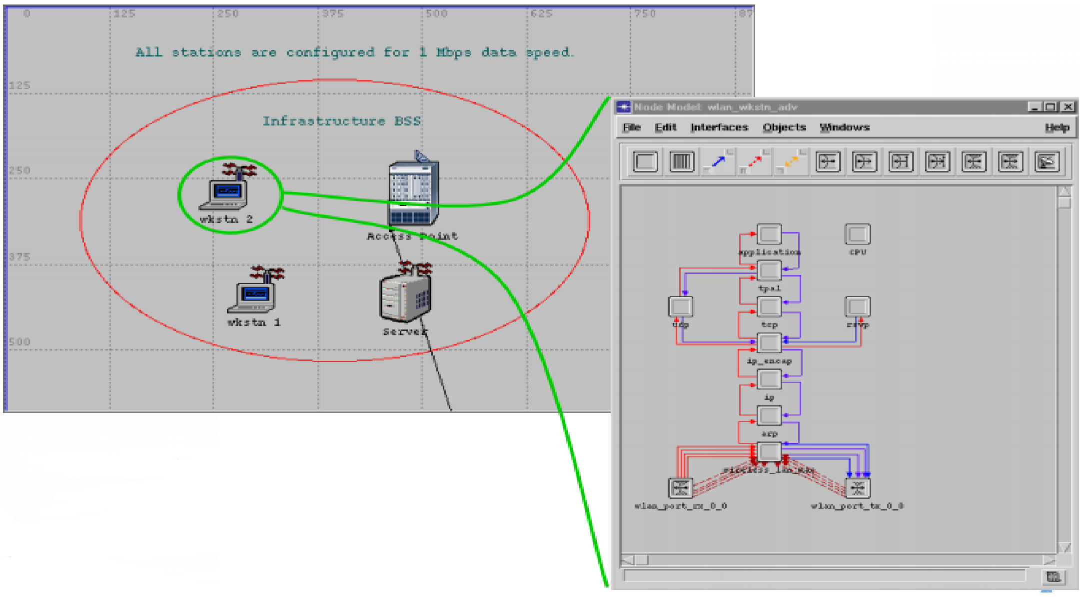


Figure 4.3 Individual Network Node Modeling[15]

The node model specifies the internal structure of a network node. Generally, network nodes include workstations, packet switches, satellite terminals and remote sensors. Node can be fixed, mobile or satellite type. The node can be modeled according OSI model which include application layer, presentation and session layer (application interface), transport layer (TCP & UDP), Network Layer (IP), Link Layer (ARP & MAC), Physical Layer (receiver & transmitter). Figure 4.4 shows that a node has been modeled internally according to OSI reference model.

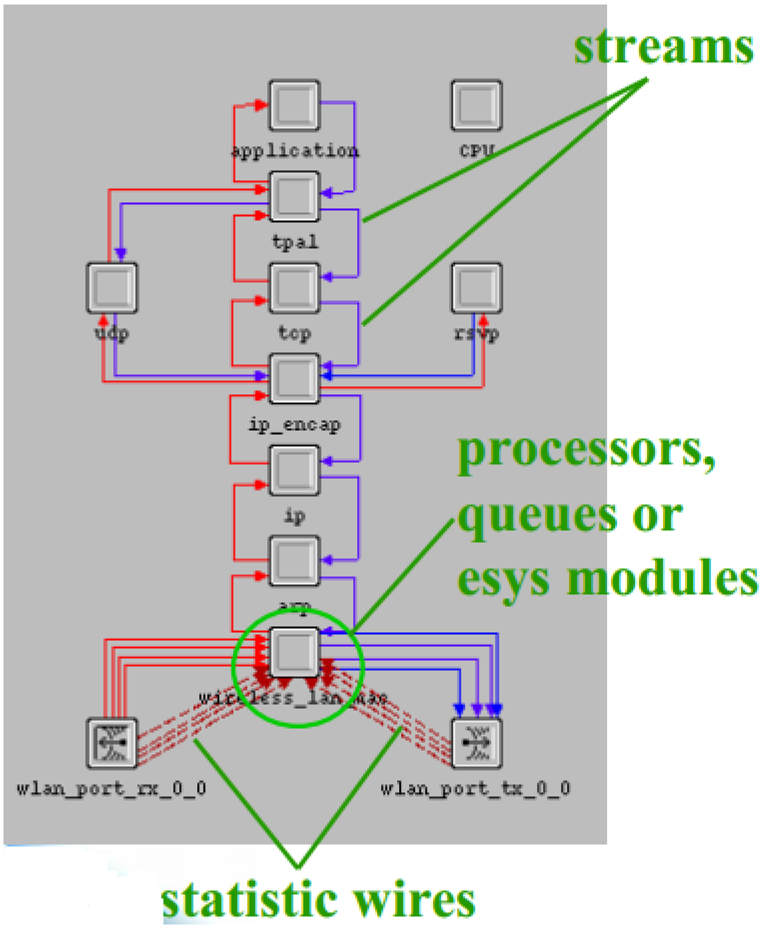


Figure 4.4 Node model with OSI[15]

4.1.3 Process Domain

Process models are used to specify the behavior of a processor and queue modules which exists in the Node Domain. A module is modeled as finite state machine (FSM) and consists of states with transition and condition between them. Figure 4.5 shows the machine states and transition in the process domain editor.

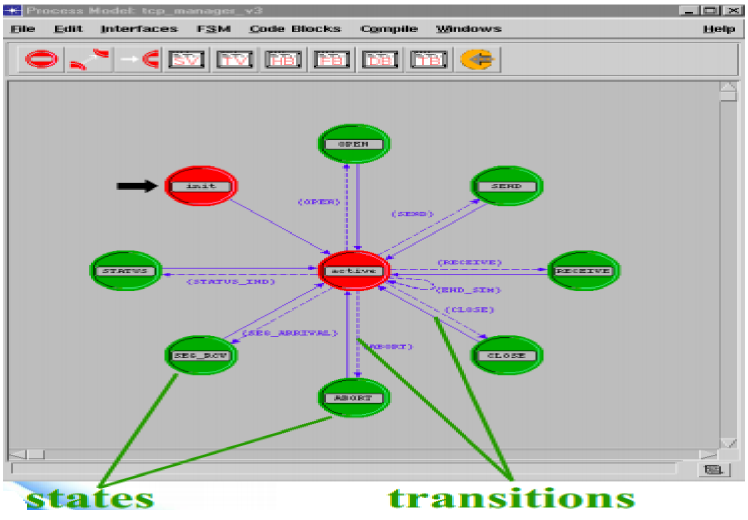


Figure 4.5 States and Transitions of a FSM in the Process domain editor [15]

The process can be edited by using the source code editor as shown in Figure 4.6 and Figure 4.7 below.

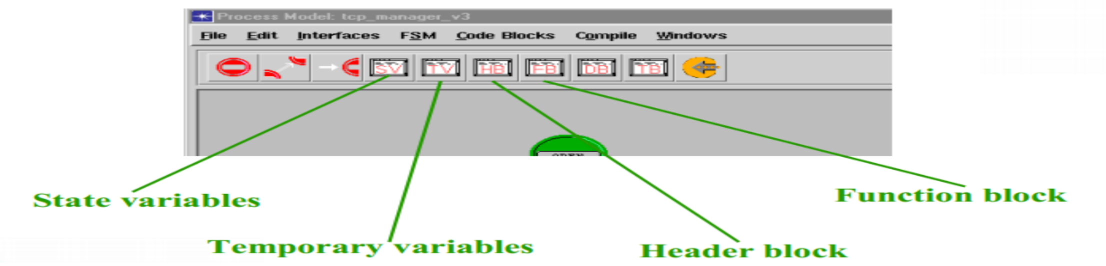


Figure 4.6 Process Editor Interface [15]

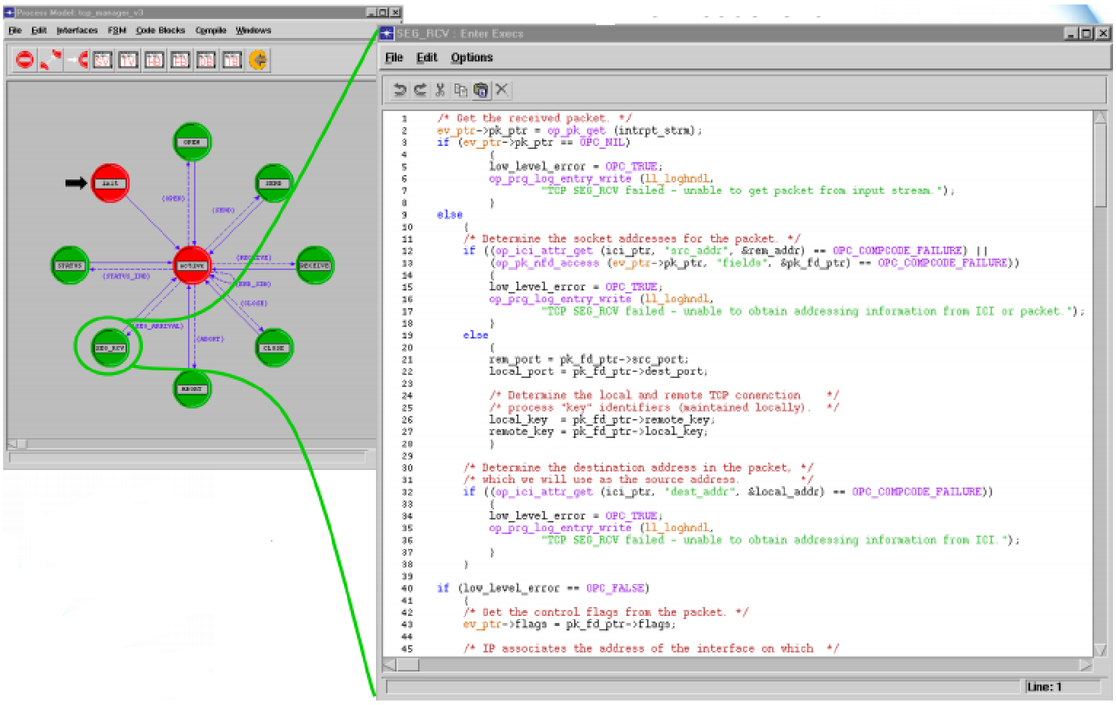


Figure 4.7 Process Source Code Editor [15]

4.1.4 Simulation Tool Design

The simulation tool of OPNET modeler can combine several low level attributes (network domain, node domain, process domain) and make series of simulation iteratively. The result will be generated by OPNET Simulator after the simulation process. Figure 4.6 shows the simulation sample.

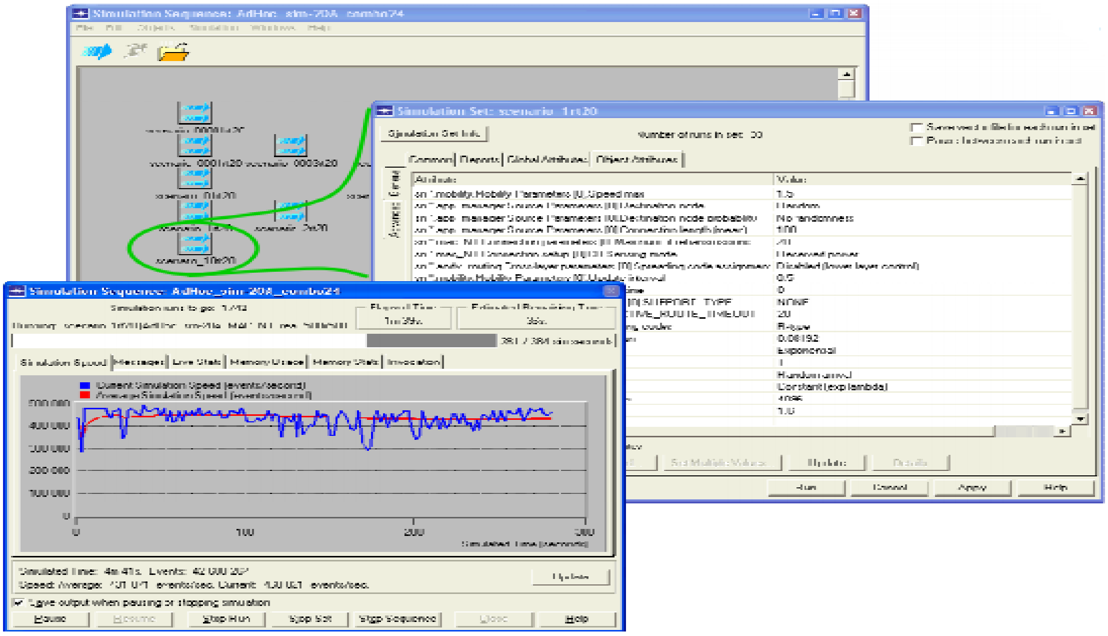


Figure 4.8 Sample Simulation and generated report in graph format [15]

4.2 Modeling UNITEN Campus Putrajaya Network in OPNET Modeler

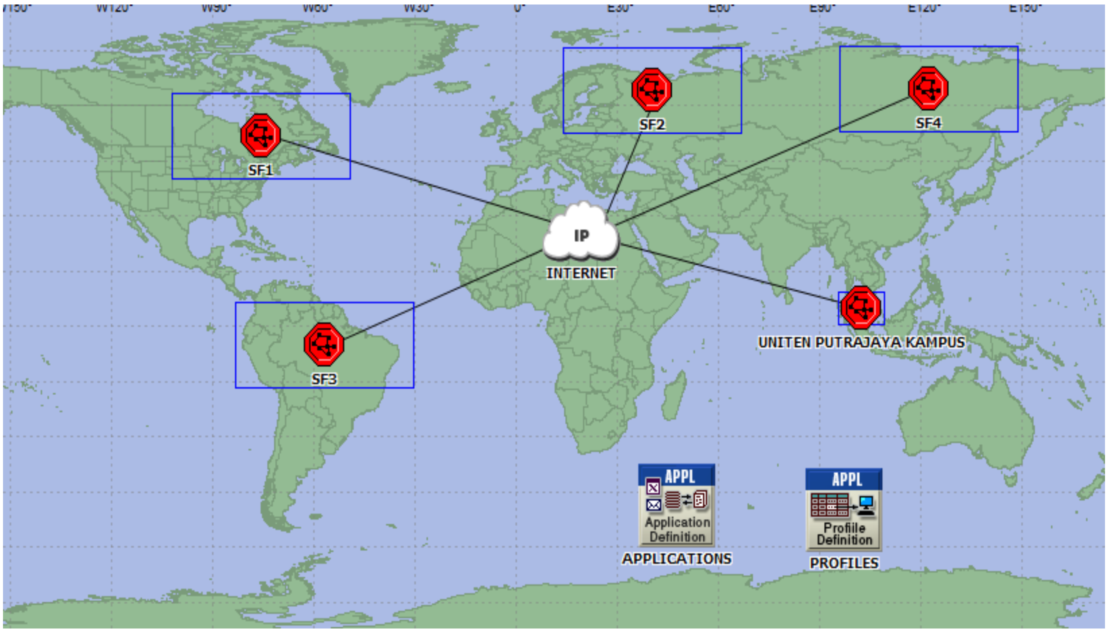


Figure 4.9 Overview of Simulation Architecture

Network architecture for the simulation consists of 5 subnetworks which are connected to internet IP Cloud via PPP_DS_1 links. SF1, SF2, SF3 and SF4 are the subnetworks where application servers are located around the world. UNITEN PUTRAJAYA campus subnetwork is the network which was constructed by using following architecture.

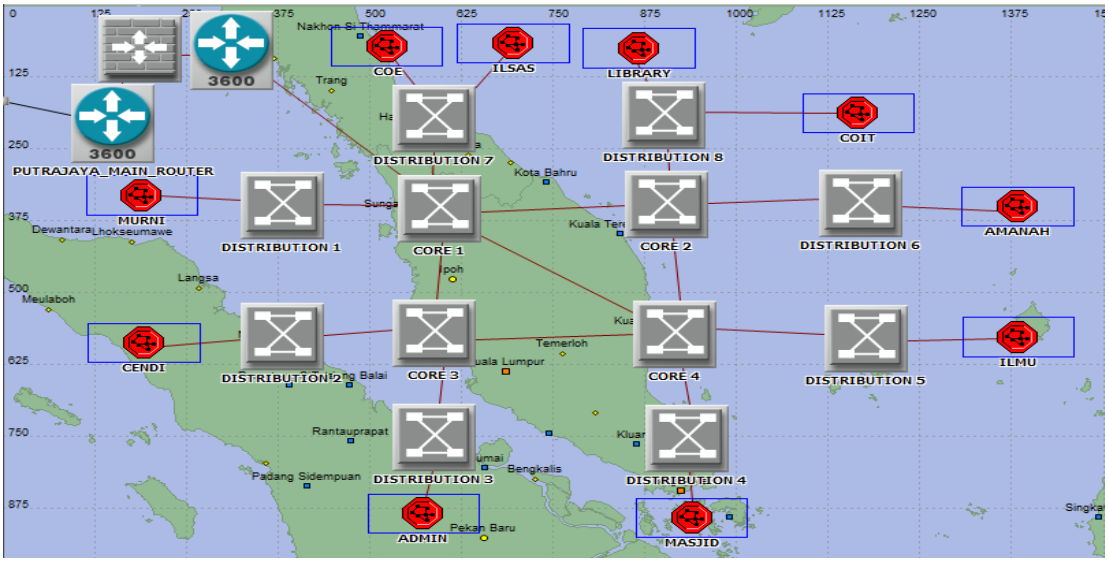


Figure 4.10 UNITEN PUTRAJAYA CAMPUS NETWORK ARCHITECTURE

UNITEN PUTRAJAYA campus network consists of 4 core switches and 8 distribution switches. Each core switches are interconnected to each other in the partial mesh fashion to provide load balancing and redundancy.

Core switches are connected to nearest distribution switches according to geographic location where the campus network will be spanning around the campus.

Each distribution switches are connected to the access subnetworks which consists of College of Engineering, Institut Latihan Sultan Ahmad Shah, Library, College of Information Technology, Kelompok Amanah, Kelompok Ilmu, Masjid Uniten, Bangunan Admin, Kelompok Cendi and Kelompok Murni.

The internet connection to outside world (WAN Link) is connected to external gateway router of UNITEN PUTRAJAYA campus network. The campus network consists of 2 routers namely internal and external gateway router. In between 2 routers, there is a firewall which provide packet filtering and Demilitarized Zone (DMZ). The node and link models will be explaining in detail in simulation parameter section.

4.3 Simulation Parameters

4.3.1 Network Simulator

The network simulator used in this project is OPNET (Optimized Network Engineering Tool). OPNET has 2 versions namely academic and commercial versions. To accomplish this project, the academic version 14.5 is being used.

4.3.2 Models used for Simulation

In OPNET, everything is assembled into the models. For example, link models, node models etc.

Table 4.1 shows the link models used for the simulation project in details.

Table 4.1 Link Models in details

Model	Source Node	Destination Node	Description
WAN Link	Putrajaya Campus Gateway Router	Internet IP 32 Cloud Node	Connect 2 Nodes running IPV4. Data Rate is 1Gbps and Packet Format is IP3_Datagram.
Single Mode Fiber Optic	Core Switch 1	Core Switch 2	Connect 2 core switches with the speed of 10Gb/s.

			Always works in Full Duplex Mode. The Packet Format is Ethernet_v2.
Single Mode Fiber Optic	Core Switch 1	Core Switch 3	Connect 2 core switches with the speed of 10Gb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet_v2.
Single Mode Fiber Optic	Core Switch 2	Core Switch 4	Connect 2 core switches with the speed of 10Gb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet_v2.
Single Mode Fiber Optic	Core Switch 3	Core Switch 4	Connect 2 core switches with the speed of 10Gb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet_v2.
Single Mode Fiber Optic	Core Switch 1	Core Switch 4	This link is for partial redundancy purpose and to

			form partial mesh topology. Connect 2 core switches with the speed of 10Gb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet_v2.
Multi-Mode Fiber Optic	Core Switch 1	Distribution Switch 1	Connect Core Switch to Distribution Switch with the speed of 1000Mb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet.
Multi-Mode Fiber Optic	Core Switch 1	Distribution Switch 7	Connect Core Switch to Distribution Switch with the speed of 1000Mb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet.
Multi-Mode Fiber Optic	Core Switch 2	Distribution Switch 6	Connect Core Switch to Distribution Switch with the speed of 1000Mb/s. Always works in

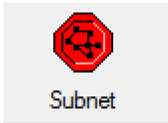
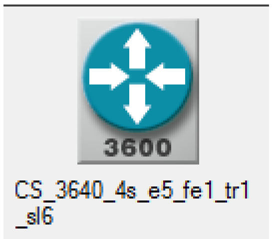
			Full Duplex Mode. The Packet Format is Ethernet.
Multi-Mode Fiber Optic	Core Switch 2	Distribution Switch 8	Connect Core Switch to Distribution Switch with the speed of 1000Mb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet.
Multi-Mode Fiber Optic	Core Switch 3	Distribution Switch 2	Connect Core Switch to Distribution Switch with the speed of 1000Mb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet.
Multi-Mode Fiber Optic	Core Switch 3	Distribution Switch 3	Connect Core Switch to Distribution Switch with the speed of 1000Mb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet.
Multi-Mode Fiber Optic	Core Switch 4	Distribution Switch 4	Connect Core Switch to Distribution

			Switch with the speed of 1000Mb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet.
Multi-Mode Fiber Optic	Core Switch 4	Distribution Switch 5	Connect Core Switch to Distribution Switch with the speed of 1000Mb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet.
Multi-Mode Fiber	Distribution Switches	Access Switches located in each subnets inside campus mentioned above	Connect Core Switch to Distribution Switch with the speed of 1000Mb/s. Always works in Full Duplex Mode. The Packet Format is Ethernet.
Ethernet Cat5e	Access Switches	Ethernet Workstations	The 100BaseT duplex link represents an Ethernet connection operating at 100 Mbps.

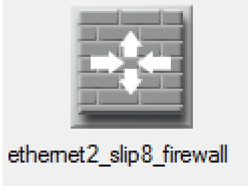
Table 4.2 shows Node Models used for simulation project in details.

Table 4.2 Node Models in details

Node	Description	Model
Core Switch	The switch implements the Spanning Tree algorithm to make sure a loop free network topology. The switch support Spanning Tree Bridge Protocol (IEEE 802.1D, Ethernet (IEEE 802.3)). The switch can operate with 3 different data rates namely 10Mbps, 100Mbpbs and 1000 Mbps. Support up to 128 interfaces or switch ports.	Ethernet128_switch_adv 
Distribution Switch	The switch implements the Spanning Tree algorithm to make sure a loop free network topology. The switch support Spanning Tree Bridge Protocol (IEEE 802.1D, Ethernet (IEEE 802.3)). The switch can operate with 3 different data rates namely 10Mbps, 100Mbpbs and 1000 Mbps. Support up to 64 interfaces or switch ports.	Ethernet64_switch 
Access Switch	The switch implements the Spanning Tree algorithm to make sure a loop free network topology. The switch support Spanning Tree Bridge Protocol (IEEE 802.1D, Ethernet (IEEE 802.3)). The switch can operate with 3 different data rates namely 10Mbps, 100Mbpbs and 1000 Mbps.	Ethernet32_switch 

	Support up to 32 interfaces or switch ports.	
Subnet icon	Subnetwork which represent the collection of workstations under the same network	Subnet 
Internal & External Gateway Router	This Cisco 3640 router represent the specific configuration of IP-based router model. Interfaces and Data Rate 1.NM-1FE-TX:1-port 1000BaseT Fast Ethernet (1000Mbps). 2. NM-4E: 4-port 10BaseT Ethernet (10 Mbps) 3. NM-1E1R2W: 1-port 10BaseT Ethernet, 1-port Token Ring, 2-port WAN (ISDN(BRI)) Interfaces. 4. NM-4T: 4-port serial, represented as 4 IP interfaces. Supported Routing Protocols	CS_3640_4s_e5_fe1_tr1_sl6_adv 

	1. Ethernet (IEEE 802.3) 2. Token Ring (IEEE 802.5) 3. Internet Protocol (IP) 4. Routing Information Protocol (RIP) 5. User Datagram Protocol (UDP) 6. Open Shortest Path First (OSPF) Protocol 7. Border Gateway Protocol (BGP) 8. Interior Gateway Routing Protocol (IGRP) 9. Enhanced Interior Gateway Routing Protocol (EIGRP)	
Firewall	The ethernet2_slip8_firewall	ethernet2_slip8_firewall

	node model represents an IP-based gateway with Firewall features and server support. Hence, it can be also called as a multihomed-server firewall node. It supports two Ethernet and eight serial line interfaces at selectable data rates. IP packets arriving on any interface are routed to the appropriate output interface based on their destination IP Address. Supported Protocols: TCP, RIP, UDP, IP, Ethernet, Fast Ethernet, Gigabit Ethernet, OSPF, BGP, IGRP	
Internet	The ip32_cloud node model represents an IP cloud supporting up to 32 serial Line interfaces at a selectable data rate through which an IP traffic can be modelled.	ip32_cloud 
Ethernet Server	The ethernet_server model represents a server node with server applications running over TCP/IP and UDP/IP. This node	Ethernet_server

	supports one underlying Ethernet connection at 10 Mbps, 100 Mbps, or 1 Gbps. The operational speed is determined by the connected link's data rate.	
Ethernet Workstation	The ethernet_wkstn node model represents a workstation with client-server applications running over TCP/IP and UDP/IP. The workstation supports one underlying Ethernet connection at 10 Mbps, 100 Mbps, or 1000 Mbps.	Ethernet_wkstn 

4.3.3 Applications and Profiles

4.3.3.1 Application Configuration Object

It has been used to define the applications, data rates and traffic generation pattern. In OPNET, Application Configuration Object can support applications like Web Browsing (HTTP), Email (POP3, SMTP, IMAP4, and HTTP), Database, VoIP, Video Streaming and Video Conferencing, FTP, Print etc. Each of the application have High Load, Medium Load and Low load of data generation rate. Each of the application can be defined and assigned values which reflect the survey result conducted to Campus Network Users.

4.3.3.2 Profile or User Profile Configuration Object

It has been used to execute the defined applications in application configuration object. The main task of this profile configuration object is to execute applications in pattern which reflect the survey result conducted to Campus Network Users.

Traffic pattern refer to how many users are using which applications at which time. For example, during office hours, office staffs are using email since it is vital for them. In this case, how big is the email generation data depends on the number of email users at particular point of time. The survey result will show whether High Load, Medium Load, Low Load should be used to determine the email traffic size.

In general, Application Configuration Object is for creating and assigning values to applications and User Profile Configuration Object is to execute these applications in the pattern which come from survey result.

Workstations and servers will be assigned with the profiles created in User Profile Configuration Object. After assigning profiles, servers will be working as application servers which accept the request from client applications.

4.4 Sample Simulation

4.4.1 Application Definition

The sample simulation is for demo purpose and it has 4 applications namely Email, Database, File Transfer, Voice over IP Call. Each of the application has their own specific data rate as mentioned below.

Table 4.3 Application Definition for Sample Simulation

Application	Data Rate
Email	Low Load
Database	High Load
File Transfer	Low Load
Voice over IP Call	Low Load

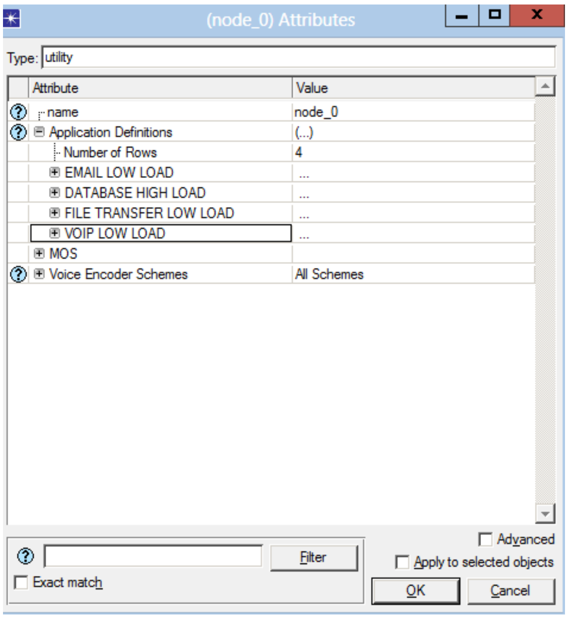


Figure 4.11 Application Definition

4.4.2 Profile Definition

The sample simulation for demo purpose will have only one profile namely UNITEN Sample Simulation. This profile will be assigned to the servers and workstation in every subnet.

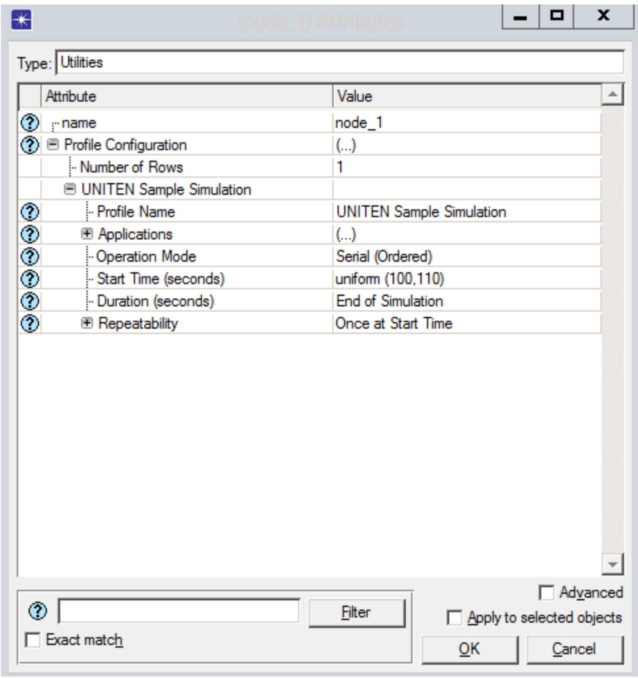


Figure 4.12 Profile Definition

4.4.3 Simulation Result

Simulation has been done for 10 minutes of the actual time with 240 users from all the subnets inside the campus of UNITEN PUTRAJAYA.

The result of simulation has been collected with 2 statistics. Global statistic which measures the Ethernet delay from servers in the server farms to the client. Individual statistic which measure at every node in the simulation environment.

4.4.3.1 Global Statistics (Ethernet Delay)

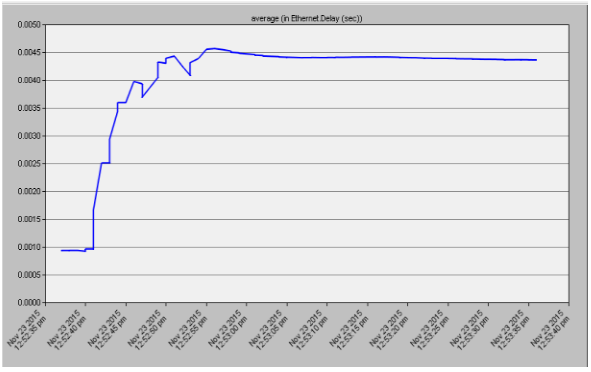


Figure 4.13 Ethernet Delay (seconds) of Global Statistics

Figure 4.13 shows that the Average Ethernet delay from servers in the server farm located all over the world to the clients in the UNITEN PUTRAJAYA campus network is 4.6 milliseconds. In the beginning of the simulation, the Global Ethernet Delay was only 1 millisecond but towards the end of the simulation, the delay keep on increasing till 4.6 milliseconds. 4.6 milliseconds is the peak Ethernet Delay for this simulation.

This is because the number of clients are relatively lesser than the actual number of clients located in the campus. For this simulation, only 240 clients has been included and the simulation time is only for 10 minutes.

4.4.3.2 Individual Statistics

4.4.3.2.1 WAN Link from Internet to UNITEN PUTRAJAYA Campus

(a) Inbound throughput measurement

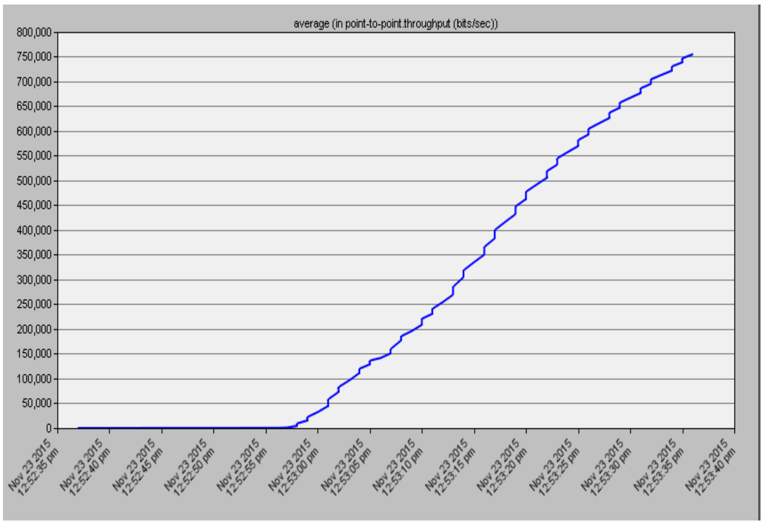


Figure 4.14 (a) inbound throughput (bits/sec) from Internet to Campus

Figure 4.14 (a) shows that maximum inbound throughput for this simulation is about 750000 bits per seconds. This measurement very depends on the number of users in the campus and number of application that they are using.

(b) Outbound throughput measurement

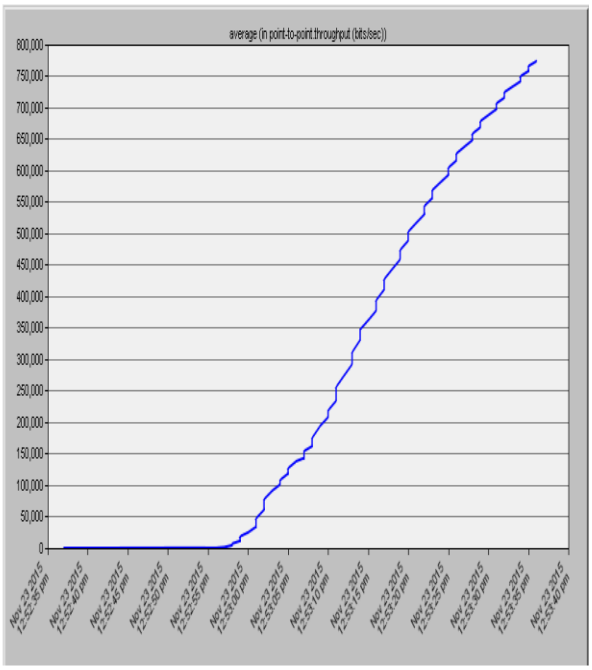


Figure 4.14 (b) outbound throughput (bits/sec) from Campus to Internet

Figure 4.14 (b) shows that maximum outbound throughput from Campus to the Internet is almost the same as inbound throughput which is 750000 bits per second. This means that there is no packet drop in between outbound and inbound traffic.

(c) WAN Link Utilization for inbound traffic

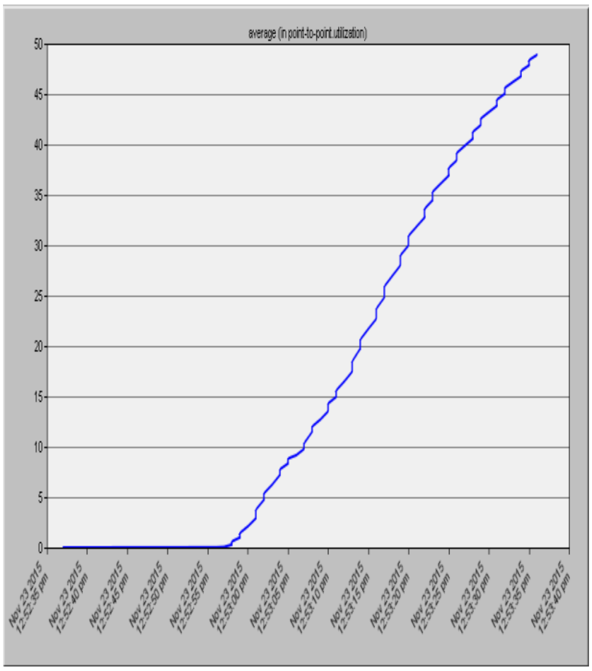


Figure 4.14 (c) inbound WAN link utilization in percentage

Figure 4.14 (c) shows that about 50% of the bandwidth of WAN Link has been utilized for inbound traffic. Inbound traffic are the traffic originated from Internet to the campus.

(d) WAN Link utilization for outbound traffic

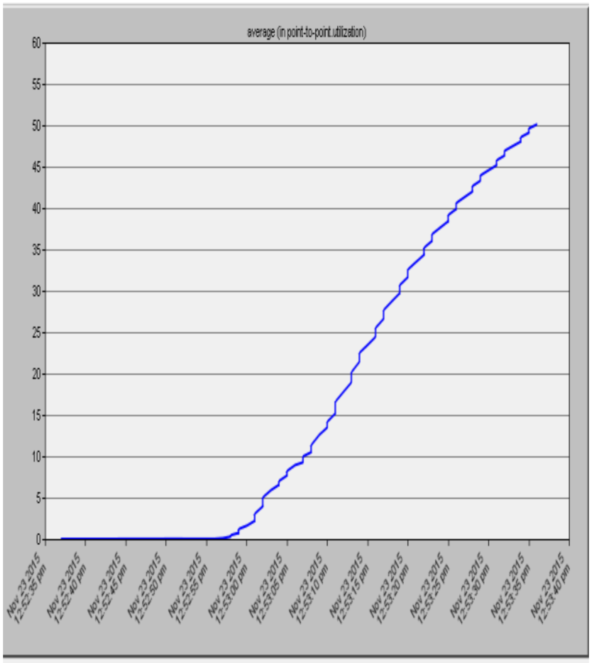


Figure 4.14 (d) outbound WAN link utilization in percentage

Figure 4.14 (d) shows that inbound and outbound WAN link utilization are almost same for this simulation which is about 50%. The utilization depends on the throughput or the number of packets which pass through the WAN Link.

4.4.4 Simulation Conclusion

The simulation result shows that the Ethernet Delay and Throughput really depends on the traffic generation pattern, the applications, the number of end users in campus, the level of internet congestion and how long the resources (links, routers, switches etc.) has been used . In other word, the duration of simulation time really shows the actual values of network congestion (Ethernet delay) and resource usage (Link Utilization). To define the applications and traffic generation pattern, a reference should be done towards the survey result. The simulation time should be long enough to show the correct result. For example, simulation with 5 applications, different traffic generation pattern, and different pattern of application execution, different number of users and different range of duration has to be done.

4.5 Flow Chart for Entire Simulation Process

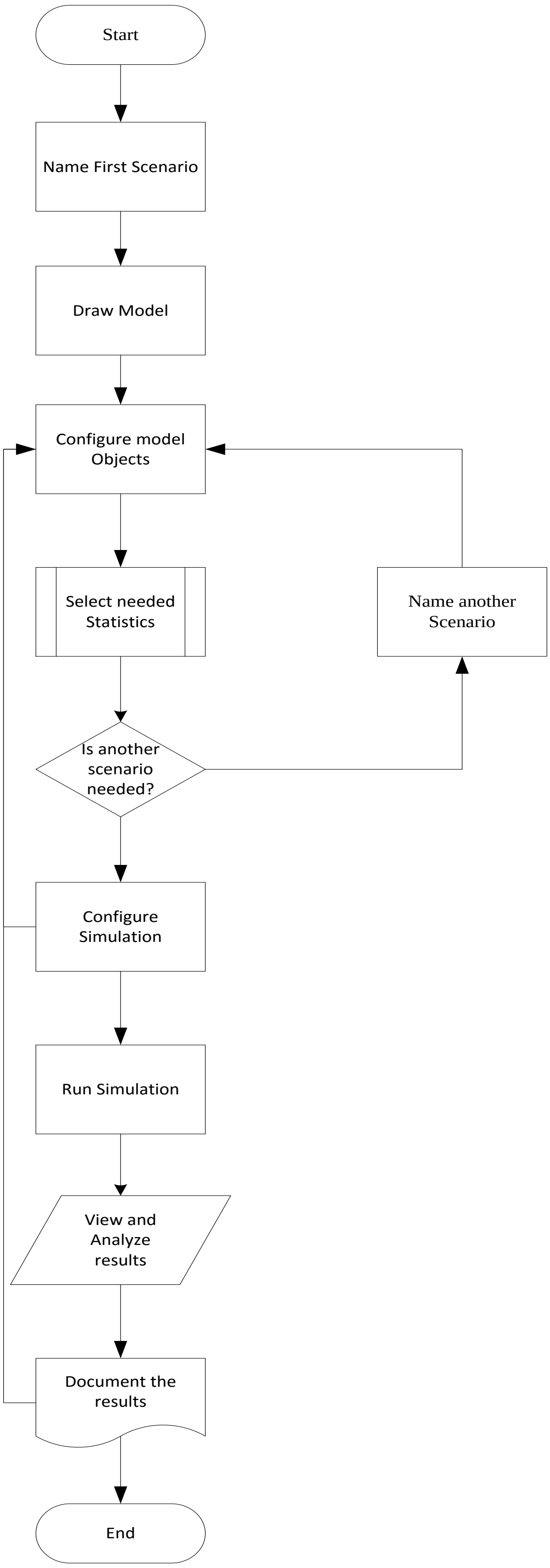


Figure 4.15 Simulation Flow Chart

CHAPTER 5

Simulation & Result Discussion

5.1 The Network Topology

5.1.1 Subnet Top Level View Topology

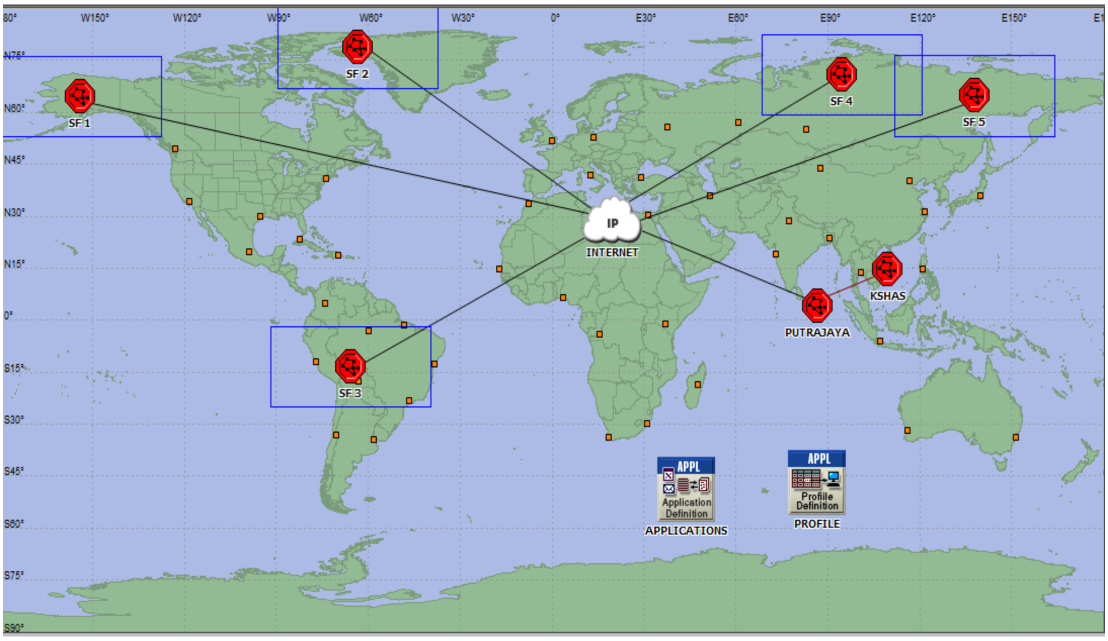


Figure 5.1 Subnet Top Level View Topology

Figure 5.1 include 5 server farms subnets (SF1 to SF5) scattering around the world map and 2 campus subnets (PUTRAJAYA & KSHAS). All the subnets are connected to internet via INTERNET object. Server Farm Subnets (SF 1 to SF5) include Servers that provide services for application which will later be used for the simulation scenarios. The 2 campus subnets (PUTRAJAYA & KSHAS) include user applications and nodes.

5.1.2 Detail Subnet Topology for PUTRAJAYA CAMPUS

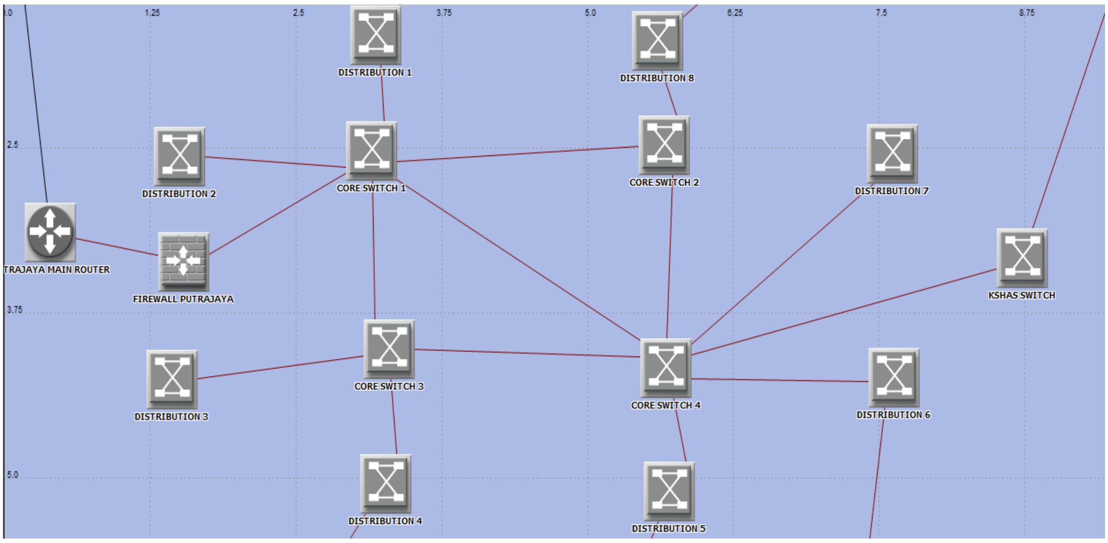


Figure 5.2 PUTRAJAYA CAMPUS Network Topology

Figure 5.2 shows that Putrajaya Campus Network Topology is made up of 4 Core Switches (Core Switch 1 – Core Switch 4) and 8 Distribution Switches (Distribution Switch 1 – Distribution Switch 8). Core Switches are connected in Partial Mesh Topology and Distribution Switches are connected to Core Switches in Start Shape Topology. On top of that, Core Switch 1 is connected to Firewall (FIREWALL PUTRAJAYA) of Putrajaya Campus Network which will filter both inbound and outbound traffic to and fro of the Campus. Firewall is connected to the main router (PUTRAJAYA MAIN ROUTER) of Putrajaya Campus Network which will be directly connected to the Stub Network of ISP. Core Switch 4 is directly connected to the Distribution Switch (KSHAS SWITCH) to Muadzam Shah Campus Network.

5.1.3 Detail Subnet Topology for MUADZAM SHAH CAMPUS

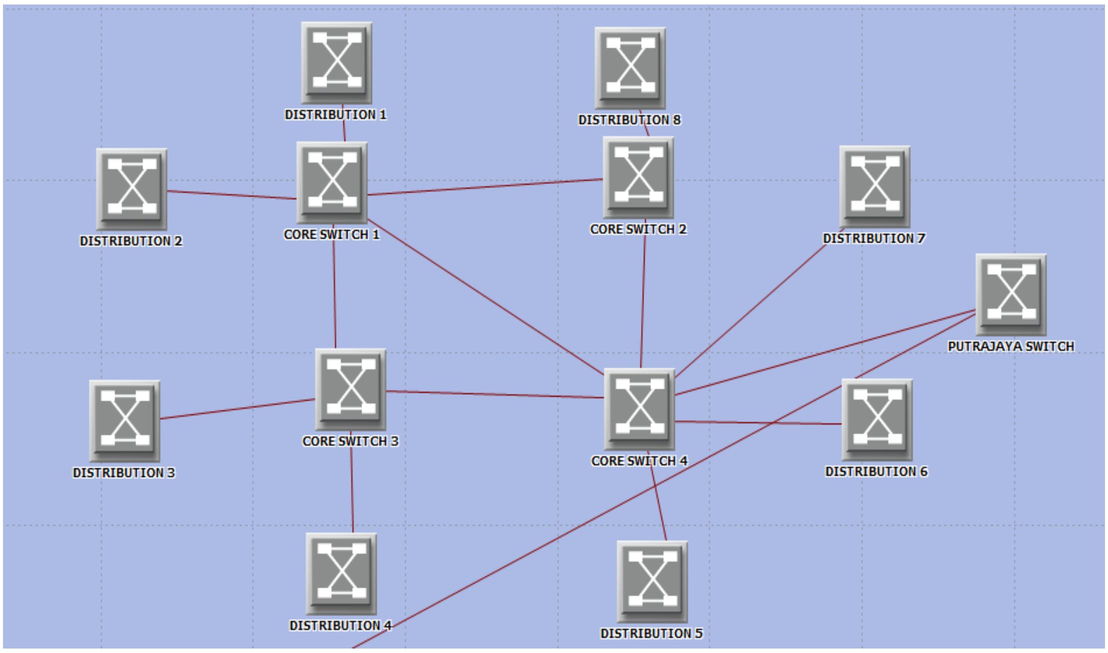


Figure 5.3 MUADZAM SHAH CAMPUS Network Topology

Figure 5.3 shows that MUADZAM SHAH Campus Network Topology is made up of 4 Core Switches (Core Switch 1 – Core Switch 4) and 8 Distribution Switches (Distribution Switch 1 – Distribution Switch 8). Core Switches are connected to each other in Partial Mesh Topology and Distribution Switches are connected to Core Switches in Start Shape Topology. Core Switch 4 is directly connected to the Distribution Switch to Putrajaya Campus.

5.2 Client Nodes on Campuses

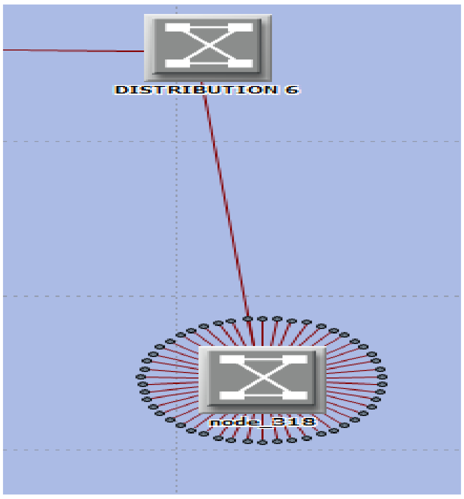


Figure 5.3 Clients Nodes Connect to Access Switch

Figure 5.3 shows that Client Nodes are connected to Access Level Switch and Access Level Switch is directly connected to Distribution Switch

5.3 Applications

Application Definitions	(...)
Number of Rows	5
DB MEDIUM	...
EMAIL HIGH	...
FTP LOW	...
HTTP SEARCHING	...
VOICE IP TELEPHONY	...

Figure 5.4 Applications

Figure 5.4 shows that there are 5 client applications to be used as the simulation parameters. 5 Applications are namely: Database Application (DB), Email Application (EMAIL), Web Browser (HTTP Searching) and Voice over IP (VOICE IP TELEPHONY). “Medium” and “High” depends on how many users are using (generating traffic) that application for simulation scenarios.

5.4 Simulation Scenarios

Table 5.1 Simulation Scenarios & Duration

# of Scenario	# of Phases & Duration
Day Scenario	1. Phase 1 (1200 Client App Users), 10 hours 2. Phase 2 (600 Client App Users) , 10 hours
Night Scenario	1. Phase 1 (1200 Client App Users), 14 hours 2. Phase 2 (600 Client App Users), 14 Hours

Table 5.1 shows that there are 2 simulation scenarios (Day Scenario & Night Scenario) and each of the scenario include 2 phases (Total Number of Users are 600 & 1200). For the Day Scenario, the duration is from 8am to 6pm (10 hours). For the Night Scenario, the duration is from 6pm to 8am (14 hours).

5.5 Measurements

In the simulation, the measurements has been done on

- Internet Delay
- WAN Link Utilization Percentage
- Main Router CPU Utilization Percentage

5.6 Simulation Results

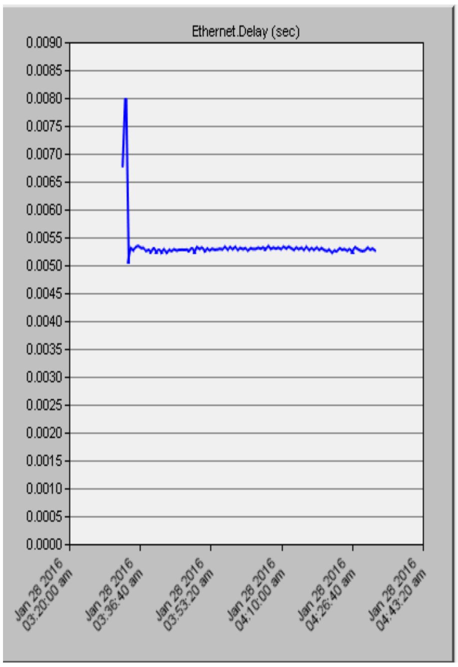
5.6.1 Tabulating Simulation Results

Table 5.2 Simulation Results in Table Form

Scenario	# of Phase	# of Clients App Users	Duration (hours)	Internet Delay (milliseconds)	WAN Link Utilization Percentage (%)	Main Router CPU Utilization Percentage (%)
Night	1	1200	14	8.2	28	0.8
Night	2	600	14	8.1	20	0.75
Day	1	1200	10	8.6	20	0.45
Day	2	600	10	8.4	11	0.35

5.6.2 Capturing Simulation Results from Simulator

5.6.2.1 Night Scenario Phase 1



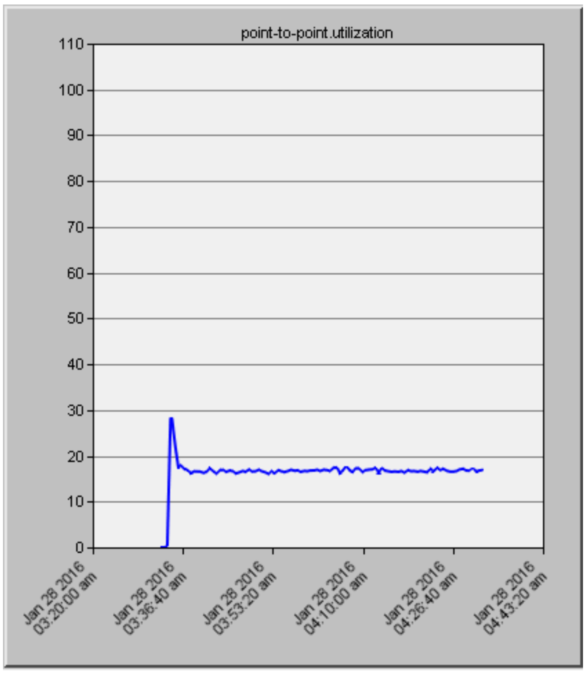


Figure 5.5 Internet Delay Figure

5.6 WAN Link Utilization Percentage

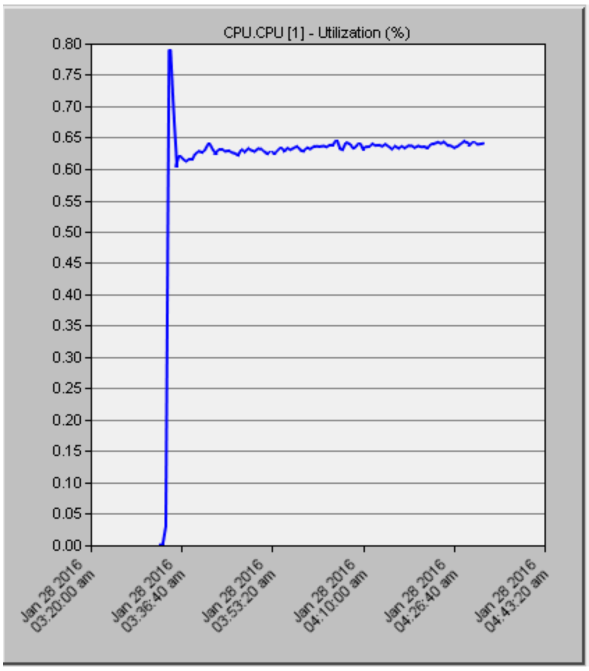
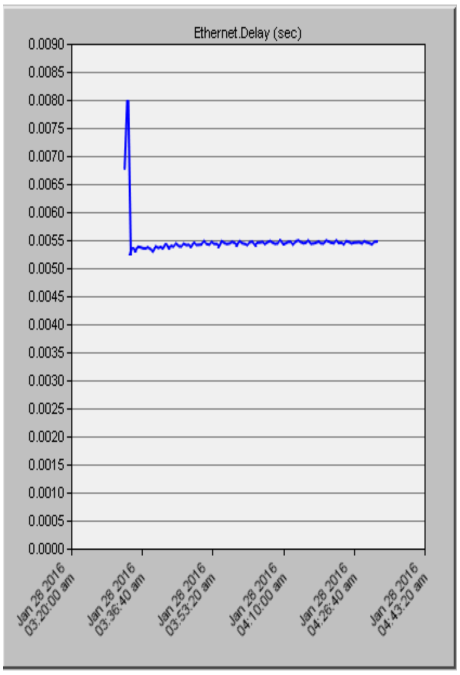


Figure 5.7 Main Router CPU Utilization Percentage

5.6.2.2 Night Scenario Phase 2



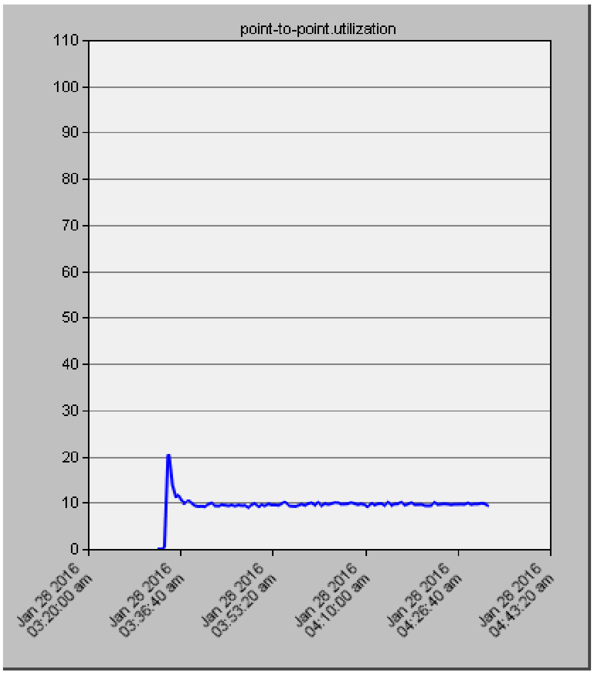


Figure 5.7 Internet Delay Figure

5.8 WAN Link Utilization Percentage

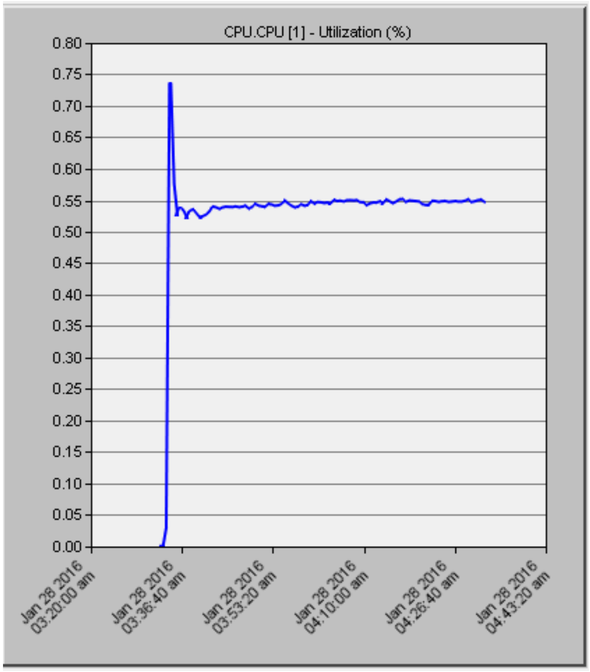


Figure 5.9 Main Router CPU Utilization Percentage

5.6.2.3 Day Scenario Phase 1

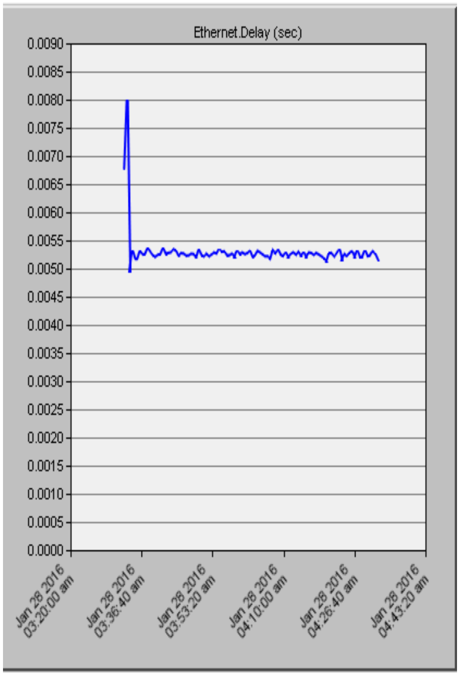


Figure 5.10 Internet Delay

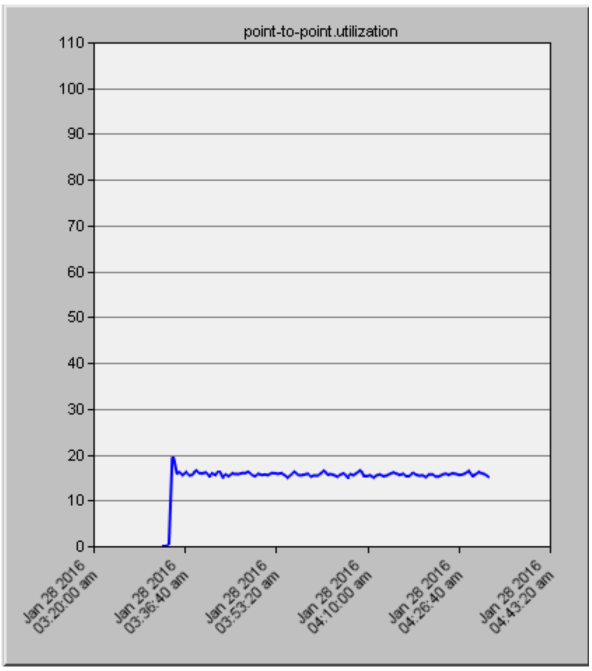


Figure 5.11 WAN Link Utilization Percentage

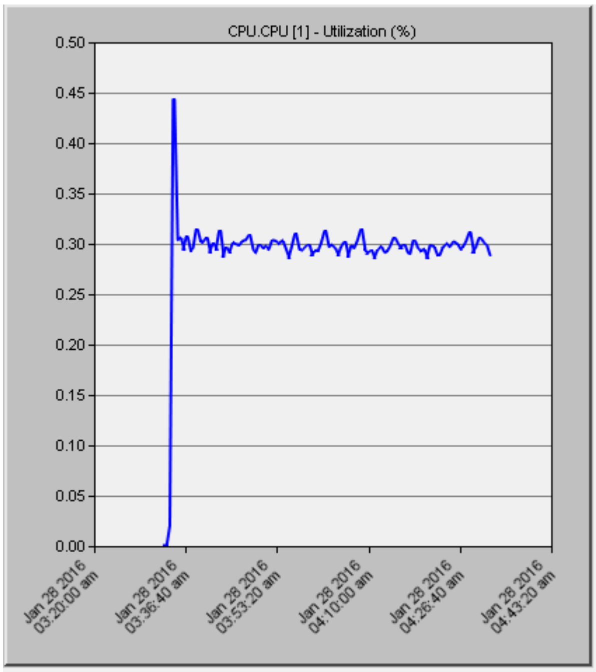


Figure 5.12 CPU Utilization Percentage

5.6.2.4 Day Scenario Phase 2

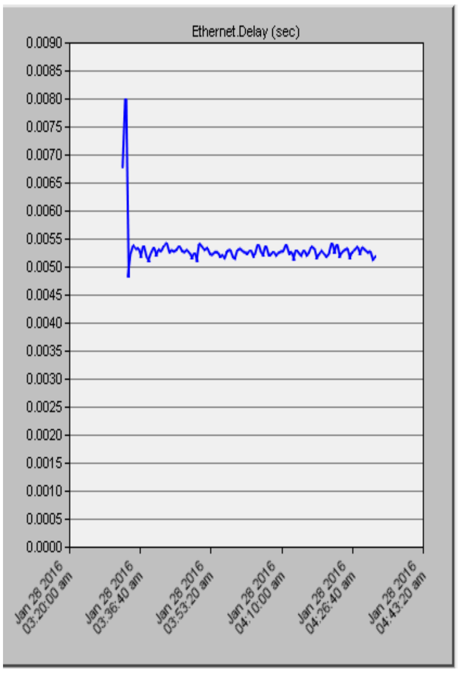
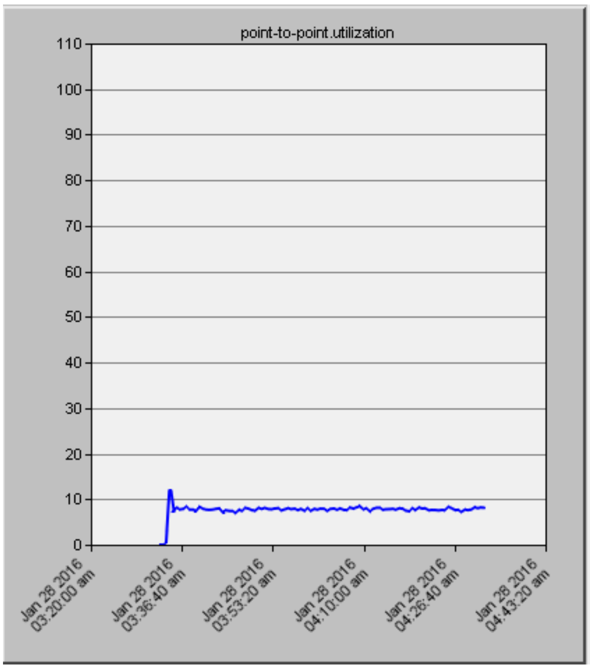


Figure 5.13 Internet Delay Figure



5.14 WAN Link Utilization Percentage

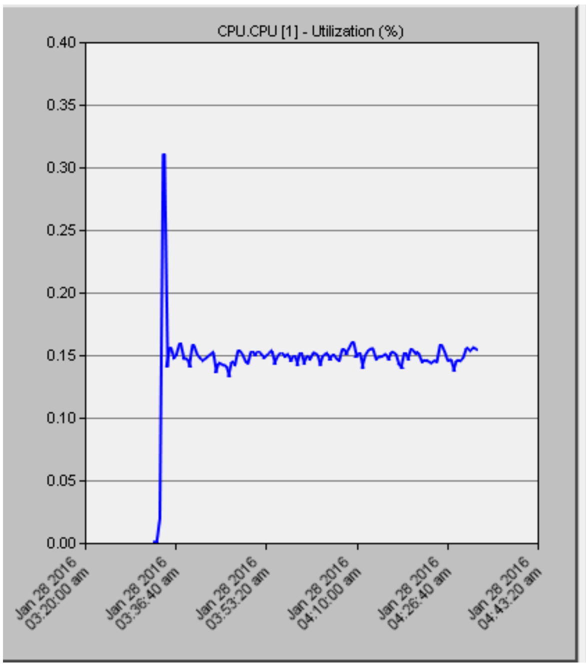


Figure 5.15 Main Router CPU Utilization Percentage

5.7 Comparison, Discussion on Simulation Results & Suggestions

5.7.1 Internet Delay

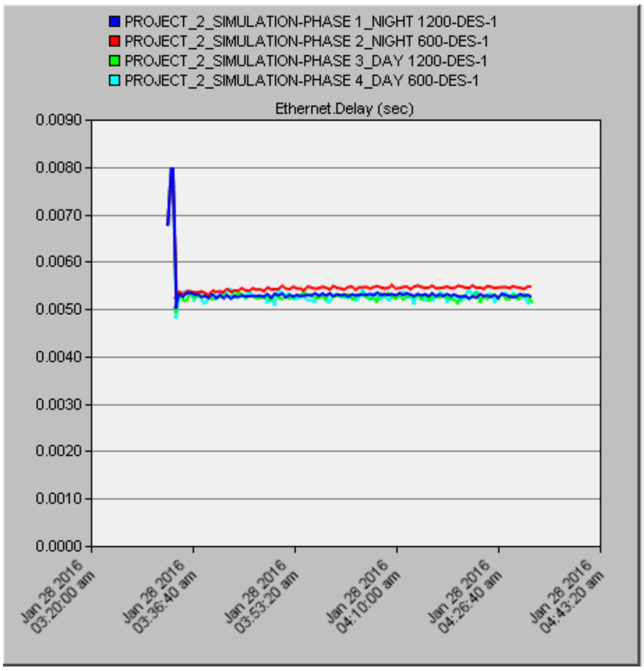


Figure 5.16 Internet Delay Comparison

The above simulation results show that Internet Delay is 8 milliseconds in both Day and Night Scenarios with Phase 1 and Phase 2. From time to time, the Internet Delay may slightly different from 8 milliseconds if there are changes like Internet traffic congestions and server loads.

5.7.2 WAN Link Utilization Percentage

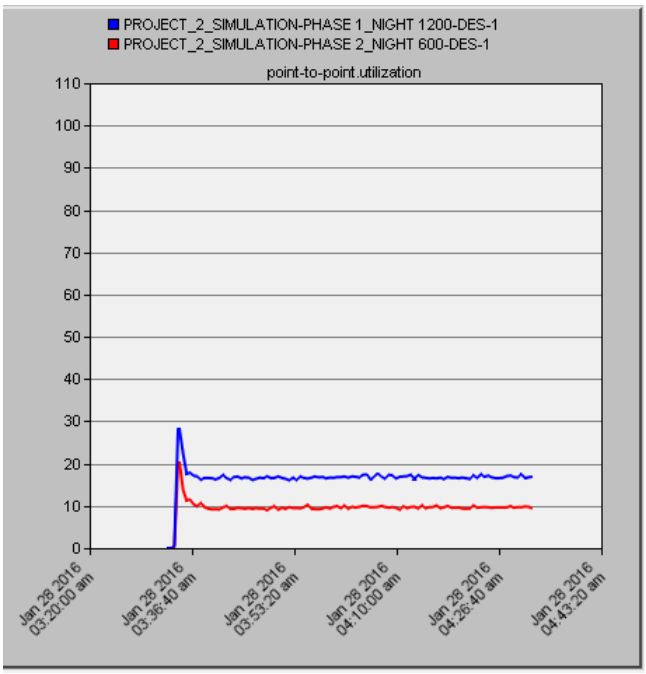


Figure 5.17 WAN Link Utilization Percentage Comparison (Night Scenario)

Figure 5.17 shows that if the number of users is 600, the WAN Link of UNITEN has been utilized for 20% and if the number of users is 1200, the WAN Link of UNITEN has been utilized for 28%. In reality, there are 12000 students and 600 staffs in UNITEN. The ratio of WAN Link Utilization Percentage to the number of users has been made by extrapolation. Extrapolation is something that we estimate for the result beyond than that of what we have. Extrapolation has been made as follows.

If # of Users = 1200

Then WAN Link Utilization = 28%

If # of Users = 12600

Then WAN Link Utilization = (12600/1200) * 28%

= 294%

If WAN Link Utilization = 28%

Then the # of Users = 1200

If WAN Link Utilization = 100%

Then the # of Users = (100/28)* 1200

= 4285 users

Suggestion

Therefore, to cater for all of 12600 users at the same time, WAN Link capacity must have to be increased for almost 3 times that what we have currently (i.e. 3 GB/s). The probability of all 12600 users will access to the internet is very low and that is the reason why we can still use the internet. If it is less than 4285 users, we can still access the internet but the speed of internet might be slow since 100% of WAN Link has been utilized.

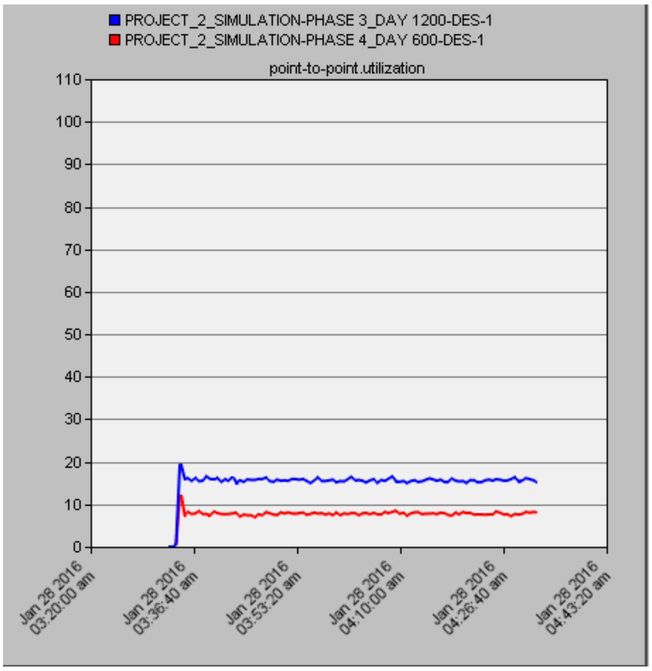


Figure 5.18 WAN Link Utilization Percentage Comparison (Day Scenario)

Figure 5.18 shows that if the number of users is 600, the WAN Link of UNITEN has been utilized for 11% and if the number of users increased to double (i.e. 1200), then the WAN Link of UNITEN has been utilized for 20%. Again, in reality, the total number of users in UNITEN is 12600. The ratio of WAN Link Utilization Percentage to the number of users has been made by extrapolation. Extrapolation is something that we estimate for the result beyond than that of what we have. Extrapolation has been made as follows.

If # of Users = 1200

Then WAN Link Utilization = 20%

If # of Users = 12600

Then WAN Link Utilization = (12600/1200) * 20%

= 210%

If WAN Link Utilization = 20%

Then # of Users = 1200

If WAN Link Utilization = 100%

Then # of Users = (100/20) * 1200

= 6000 users

Suggestion

Therefore, to cater for all of 12600 users at the same time, WAN Link capacity must have to be increased for more than 2 times that what we have currently (i.e. 2 GB/s ++). The probability of all 12600 users will access to the internet is very low and that is the reason why we can still use the internet. If it is less than 6000 users, we can still access the internet but the speed of internet might be slow since 100% of WAN Link has been utilized.

5.7.3 UNITEN Main Router CPU Utilization Percentage

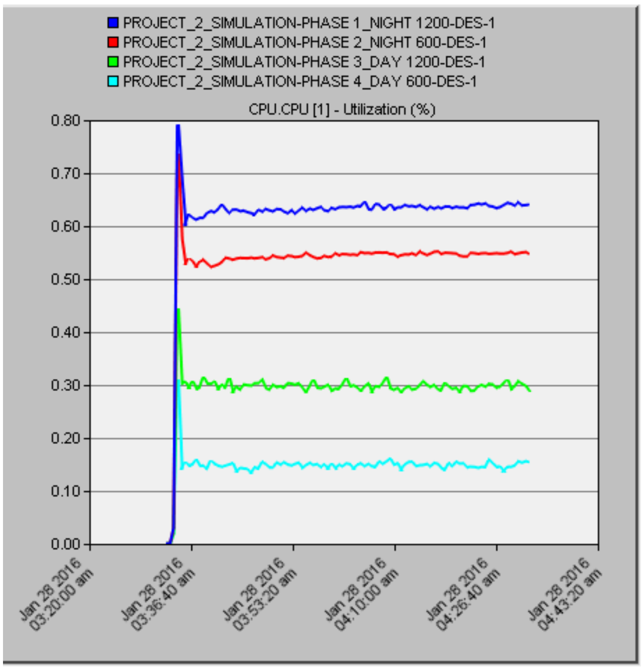


Figure 5.19 Main Router CPU Utilization Percentage Comparison

Figure 5.19 shows that highest percentage of utilization is 0.8 % while the total number of users is 1200. In reality, the total number of users on campus is 12600 and the extrapolation has been done as follows.

If # of users = 1200

Then Main Router CPU Utilization = 0.8 %

If # of Users = 12600

Then Main Router CPU Utilization = (12600/1200) * 0.8 %

= 8.4 %

If Main Router CPU Utilization = 0.8%

Then # of Users = 1200

If Main Router CPU Utilization = 100%

Then # of Users = (100/0.8) * 1200

= 150,000 Users

Suggestion

To utilize 100% of Router CPU, we need 150000 users to generate the traffic at the same time. UNITEN currently has only 12600 users and therefore, the router does not need to be changed to provide better internet speed.

CHAPTER 6

Conclusion

Simulation becomes one of the important proof of concept techniques nowadays. The whole network can be simulated in the computer by using real time situations and scenarios. A technique of implementing the network in the computer is called network simulation. From this, the nature of the network can be calculated either by using mathematical formulae for the network entities or by capturing, replaying the observations from a real production network.

The simulation process help network administrators and professional to avoid unnecessary actions such as reinstalling, reconfiguring the network after network was implemented. The information on UNITEN Campus Network Architecture has been collected which helps a lot in modeling the network in the simulator. The analysis on current Network Architecture and the problems relating to current network architecture has been done.

The network simulator called OPNET was chosen to be the simulator for the entire project. The comparative study of popular network simulators has been done and all of them have their pros and cons. Therefore, the choice of network simulator was very important step and the main reason to choose is its capability and user friendliness. By simulating network before it is actually implemented, the administrators of the network will benefit for saving time and cost.

This paper discussed various simulation methods, simulation tools and simulation scenarios by using Universiti Tenaga Nasional Campus Network which include both Putrajaya Campus Network and Muadzam Shah Campus Network. Furthermore, the discussion has been done on network traffic generation patterns and their respective applications as simulation parameters. The network traffic generation patterns can strongly affect the network behavior which include end to end delay and network congestion as discussed in chapter 5.

The main purpose of doing this simulation project is to identify the reasons why campus internet access is slow and to generate suggestions. The type of applications that UNITEN network users has been using are discussed with scenarios and simulation has been done with those scenarios.

The focus of this simulation project is based on the application layer (Layer 7) and physical layer (Layer 1). In other words, the IP addressing Scheme (Layer 3) and the VLANs (Layer 2) were not discussed in this paper since this paper focus on the application on the campus network, the traffic generation pattern of the applications and the effect of the traffic generation pattern on the network behavior. Furthermore, the proxy servers were not discussed on this paper due to the limitations of simulator software.

To conclude, based on real time ping results and simulation results, to cater all of the users, the WAN link capacity of the campus have to be upgraded to 3 times that of current capacity since the bottleneck of the campus network has been identified on the WAN Link of Putrajaya Campus which directly connected to stub network of ISP.

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