

**Performance Modelling of UUM Local Area Network
(wired)**

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University of Utara Malaysia

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**Performance Modelling of UUM Local Area Network
(wired)**

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Master of Science (Information Technology)
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By

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ABSTRACT

Slow network connection in accessing resources is a common complaint on a computer network that has switches as dominant network equipment, when certain nodes are heavily loaded with clients more than their capacity. In this study a simulation model was developed and validated for the University of Utara Malaysia wired Local Area Network. The effect of network parameters such as the processing time and the packet arrival rate on the performance metrics such as throughput, end to end delay and utilization of the servers and switches on the network was investigated. The analysis of the results from the simulations carried out can assist the management of computer centre that manages the network in identifying the bottleneck node on the network and for future network capacity building.

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Taiwo, Ayankunle Adegbite
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LIST OF ABBREVIATIONS FOR THE DISTRIBUTION SWITCHES

Switch B1	COMPUTER CENTRE
Switch B2	FSKP/FKBM
Switch B3	FPP/FSK
Switch B4	RACK A PERPUSTAKAN
Switch B5	BENDAHARI
Switch B6	CONVENTION CENTRE
Switch B7	KOLEJ EON
Switch B8	PALAPES
Switch B9	BKP
Switch B10	FWB/FPAU
Switch B11	BUKIT KACHI
Switch B12	KOLEJ B.MUAMALAT
Switch B13	FTM
Switch B14	FACULTY OF ECONOMICS
Switch B15	PPK
Switch S	CORE SWITCH
Switch X	DATACENTER SWITCH 1
Switch Y	DATACENTRE SWITCH 2
Switch Z	SWITCH AT THE DMZ

CHAPTER ONE

INTRODUCTION

Computer networking enables people or devices to communicate with one another. The telephones are networked in the GSM and public telephone systems. Data networks connect several computers, making it possible for them to connect and exchange data. A data network can simply be created by connecting two computers together with a cable.

A voice and data network Local Area Network (LAN) is a collection of individual networks connected by network equipments to function as a single large network known as internetworking. Local Area Network makes it possible for multiple users in a small geographic area to access shared resources, exchange files and messages on a data network. WANs interconnect the LAN to make it possible for geographically dispersed users to share information. It is slower in comparison to a LAN, and usually requires a connection request in order to send data. This is made possible by service providers with a monthly tariff paid (Teare, 2008).

In a computer network that has switches as dominant network equipment, data packets are sent on a shared link via the switches. The switch will have to make a decision on which packet goes first. In a packet switched network a switch could be designed to service packets on a FIFO basis, so as to ensure that packet flows receive a specific share of the link's bandwidth and that the packets are not delayed in the switch for more than a certain length of time. When a network allows such packets flow to request the above treatment, it is said to

support Quality of Service (QoS). In a case where switches are dominant in a network, the switches will have to multiplex incoming packets streams into an outgoing link. Sometimes when switches receives packets faster than what the shared link can accommodate then it will buffer them in its memory, but should it receive more packets than it can send then the packets are dropped. A switch operating in such manner is said to be congested (Odom et al., 2008). There is a need to do a performance analysis of such network.

Performance models of computers and communication network have been studied and used for quite a while, in order to guide computer network design and assist optimization. In the event of slow performance of a network, analytical modelling and simulation can be applied to actually analyze it performance instead of guesses. A model gives an organized procedure for the analysis of a problem (Theelen, 2004). The formal models of performance necessary for the efficient, reliable design and optimization are stochastic (queuing-based model) and simulation.

1.1 PROBLEM STATEMENT

IT infrastructural upgrades are expected to improve the performance of a communication network. But expansion of the network with additional network nodes, and an increasing number of users on the network inhibits generic problems in any communication network. When traffic bottleneck nodes exist on the network, congestion is imminent in some sections. Slow network connection in having access to needed information is a common complaint from users on such a network. In addition, inadequacy of network management tools to measure the performance of the network is a prominent challenge to network engineers and

management. There is a need to do a performance analysis of the network and avoid issues and complexities that is associated with a growing and expanding computer network.

1.2 OBJECTIVE

The main objective of this study is to develop a performance model of the University of Utara Malaysia (UUM) wired Local Area Network (LAN). This shall be achieved through the following specific objectives:

1. To develop a simulation model for UUM wired Local Area Network (LAN).
2. To gather the operational data of the UUM wired LAN.
3. To simulate the future behaviour of the network.

1.3 SCOPE OF STUDY

The scope of this study is but limited to the development and validation of a performance model of a computer network. The Local Area Network LAN (wired) of University of Utara Malaysia was selected as a case study. Simulation modelling technique was used to model the network topology, while Omnet++ was used as the network event simulator/tool.

1.4 SIMULATION METHODOLOGY

The simulation methodology used in this study is similar to Law & McComas (2001) approach to modelling. This is also with a guide from Barton (2001). The steps are as displayed in Figure 1.

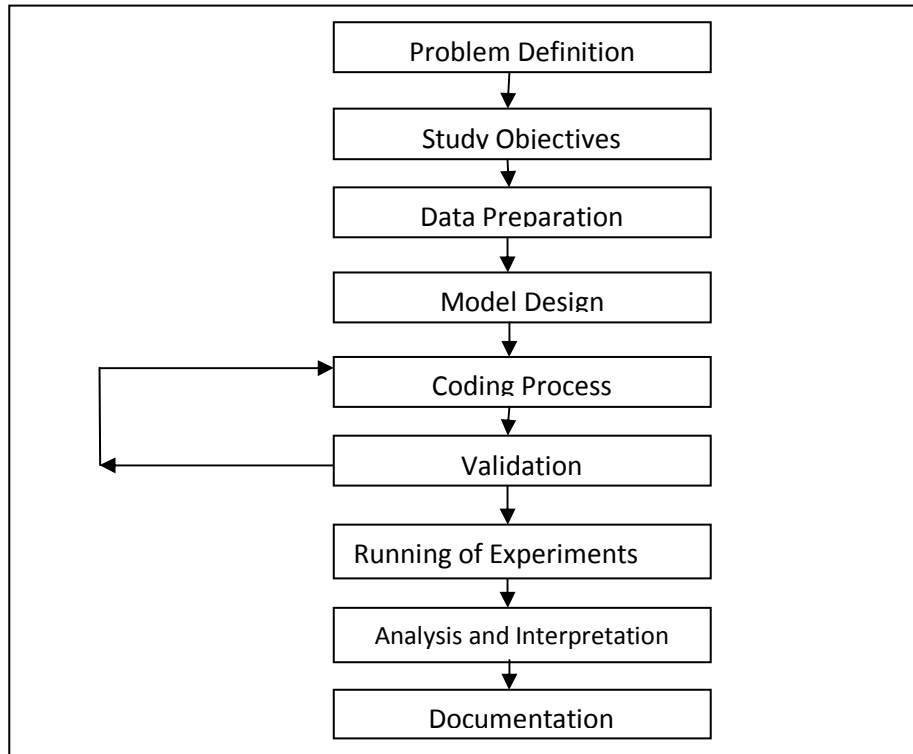


Figure 1: The Flow Diagram of the Simulation Methodology

1. Set Problem Definition: An identification of the problem was made.
2. The Objective for the study was identified and stated.
3. Data preparation: Meetings and short interviews were scheduled with the network engineers and NOC staffs in the computer centre in order to collect operational data. The data collected includes: the packet size, speed of the communication links between each nodes on the network. The independent variables are the processing time, no of users while dependent variables are throughput, end to end delay.
4. Model Design: A definition of the topology of the domain area UUM LAN was made. The information collected from the NOC was used to state the structure of the network. A freehand design model was first developed.

5. Coding: - Translating the design to a computer model to analyze the network as a Jackson Open Network. Queuing model techniques shall be used to model the M/M/c (finite and infinite capacity of the distribution and core switches on the network) queuing network model using Omnet++ as the network event modelling simulator.

6. Validate the model: The computer model was validated by making comparison between the results (parameters and values) of the model and the available data collected from the Computer centre. The percentage of the improvement or the deviation from the collected data from Computer centre will be measured.

7. Running of Experiments: Simulation runs of the model using the event Simulator for about 30 runs were made.

8. Analysis of the Simulation: Parameters were adjusted for capacity planning and prediction during simulation.

9. Documentation: A report of the outcome of the analysis was made.

There is a possibility of simulation models not to achieve the intended goal. This can be avoided when the simulation model is organized intelligently to mimic the likely performance of the real system. The very most important key to consider is the planning and design of the model (Barton 2001). The results of a poor design model can be misleading. Steps that lead to a good design of a model will take the following sequence as proposed by Barton (2001).

1. Define the goals of the experiment.

The goals can be constructed hierarchically in graphics so as to identify the resources necessary in the study

2. Identify and classify the independent and dependent variable

The desired values can be noted as the independent variables while the performance measures of interest which are to be measured are the dependent variables.

3. Choose a probability model for the behaviour of the simulation model

This step decides the hypothesis to be tested.

4. Choose an experiment design: The stage entails the model setting to run. The value of the parameters has to be specified.

5. Validate the properties of the chosen design: This stage entails checking the model mathematically.

1.5 SIGNIFICANCE OF STUDY

The significance of this study is development of computer simulation model for the UUM Local Area Network. The model will assist in evaluating the present and the future performance of the network. The model will also be of assistance in network capacity planning. Management can make use of the resultant values of the simulation to make capability projection of the IT network infrastructure to determine the most cost-effective network configurations that will result in the best network performance. Furthermore the research study will assist in identifying some problem area on the network.

1.6 ORGANIZATION OF THE REPORT

In chapter two recent works are discussed, including various techniques of performance modelling, types of simulation models. Some available simulation tools are also mentioned. A brief description of OMNet ++, the simulation system used to model the LAN is presented and the background of the UUM Local Area network is also shortly discussed in chapter three. Chapter four explains the development of the simulation model, its validation and other

processes in developing the model. The predictions of the simulation model for performance are discussed in chapter five. This includes the results gathered and their interpretation. Chapter six concludes the study with a short summary of research contribution and proposal for future works.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Various approaches to performance modelling in past researches are discussed in this chapter. The approaches show the relevance of Performance modelling to a specific research problem, situation or industry. The types of simulation models, tools available and how to build a successful model is reviewed.

2.2 MODELLING TECHNIQUES OF COMPUTER NETWORK

Construction of models for the evaluation of performance properties is called performance modelling. The precise assessment of the performance properties is known as performance evaluation or performance analysis. Performance Models are developed with the intention of investigating a specific aspect of a system. Theelen (2004) described Performance Modelling as the construction of models for the evaluation of performance properties. Thakkar et al. (2008) classified performance modelling techniques as measurement (operational), analytical and simulation based techniques. But analytical, simulation and operational are often used in performance modelling.

2.2.1 ANALYTICAL MODELING

Puigjaner (2003) characterized analytical modelling techniques as, Petri nets, Queuing networks, Reward models, Process algebras, Markov and semi-Markov chains. However these can be used to find solution of performance metrics. The authors modelled a TCP/IP system that composed of two Internet Service Providers (IPs) connected by a link at 2 Mbit/s. Each ISP manages 5 email stations and a sixth one delivering files. Variations were made on the buffer size of the service providers to reduce losses on packets.

A new analytical approach to modelling the performance of Wireless Mobile Networks was developed by Fang (2005). An analytical formula was derived for call blocking probability, call dropping probability, handoff probability, handoff rate, and the actual call holding times for both complete and incomplete calls on the network. The analytical model for the probabilities was derived by evaluating integrals. The authors also used rational approximation (Padé approximation) for the probability distributions of the involved time variables. All computations are reduced to finding the high-order derivatives of rational functions. The computational complexities were thus reduced. The approach was used to model the performance of mobility management schemes under fairly general assumptions in (Fang, 2002; 2003).

Padhye et al. (2000) developed an analytical model to measure TCP Reno performance on the computer network. The model is a stochastic model of TCP protocol congestion control on the network that yields a relatively simple analytic expression for the send rate of a saturated TCP sender. A comparison of the real world TCP connection was made and the model performed better with minimal time-out. The comparison revealed that time-out has a significant impact

on the performance of TCP protocol. Rahman & Ghazali (2008) modified the model developed by Padhye et al (2000) to improve its friendliness so as to improve the performance of the computer network. A simple expression for calculating the throughput of a bulk transfer TCP flow was also derived. This makes it easy to measure the throughput and the Round Trip Time (RTT). The study was done using the dumbbell topology and without application to real life scenario.

Analytical models can be developed to measure the performance of a call centre from a real time queuing science characteristics point of view (Demiriz, 2006). The models were designed with the agents skill set involved. This was done without applying it to real life situation. Avramidis and L'Ecuyer (2005) made key notes in analytical models for a call centre management and described the decision problems commonly encountered in call centre management. Previous analytical models developed in application to call centre are confronted with some problems. Examples are the main themes of uncertainty throughout the decision hierarchy, the operational complexities and relationships between decisions. The authors' study revealed that the high operational complexity and the prevalent uncertainty in a call centre suggest that simulation modelling and simulation-based decision-making could have a central role in the management of call centres for better performance.

Lee et al. (2007) used a general class of Regression models and Neural Networks to predict the performance of the network in a parameter tuning experiment. The experiment was used to solve the increasing system and algorithmic complexity combined with a growing number of tuneable application parameters that is of great challenge for analytical performance

modelling. A. Regression offers greater transparency and statistical understanding while neural networks offer greater usability and automation.

Another technique that could be used in modelling is Markov chains. Most of the analytical models are constructed as underlying Markov chains. The Markov chain technique provides most general solution in modelling. The reason why the direct Markov method is not the universal solution approach is simply their size (Puigjaner, 2003).

2.2.2 SIMULATION MODELLING

Simulation models are widely used because it can handle the complexities of large networks. The ease of use, intuitive understanding and no theoretical limitation also makes it a widely selected choice (Puigjaner, 2003). Simulation modelling can be easily used to obtain the objective of locating bottlenecks and evaluate alternatives in system. Kiran et al, (2000) developed flexible model to analyze a new airport. The model was flexible enough to allow modification of different parameters in the system. Although the airport modelled was not in operation yet, the performance of the system under “what if” scenarios can easily be evaluated using simulation modelling technique.

Simulation modelling can also be used to model software descriptive process model (Park et al., 2007). Software Process Engineering Metamodel (SPEM) and Discrete Event System Specification (DEVS)-Hybrid was used. A three step list was provided for deriving the simulation model. Which are mapping, modelling, and transforming. The elements of SPEM and DEVS-Hybrid were mapped. And a descriptive process model was developed using UML

based on SPEM. A DEVS-Hybrid simulation model was formed by using transformation rules. The approach employed reduced the cost of simulation model development because the descriptive model was automatically turned into a simulation model.

Alberti et al. (2006) developed a simulation model for two Combined Input-Output Queuing (CIOQ) switch architecture. The switch architectures were previously developed by (Motoyama & Santos 2004). The switches comprise of single buffer CIOQ and class based CIOQ. By varying the input-output ports, the number of internal links and the offered load. The simulation models were developed using Arena 5.0 and the validated models proved that Santos and Motoyama architectures are very efficient, with small blocking probabilities and queuing requirements. Cover blocking probability, mean and maximum queuing occupation for several switch dimensions and load intensities was measured. Each of the switch ports was tested against different load capacities with a queue of FIFO. The analyzed result shows good improvement in performance with Input Queuing in terms of occupation reduction and decrease of Head of Line Blocking (HOLB). This was under the assumption of a steady state. In study, simulations were also made to exceed the transient state.

Another approach to simulation modelling is the use of Base Object Model (BOM) (Moradi et al., 2006). BOM is a new standard for defining reusable and compassable simulation components. The introduction of BOMs into the simulation brings about an approach that is faster and more efficient than the present simulation creation process. A process model for CBMD was developed using divide and conquers method. The major idea behind this approach is to bring to reality the intention a simulation developer has in mind by breaking it down into small parts and components. The developer can conclude in three parts process

which is Discovery, Matching and Composition (DMC). The study focused on creating a Component-based simulation model development (CBMD). This is to make available to simulation modellers and developers set of services to improve the simulation development and execution process.

Kher (2000) used simulation modelling to measure the human resources required for the optimal customer service delivery rate. Parameters taken into consideration for the study was the job processing time for highly valued customers. And a mean processing time for the serviced customer. 99% better customer service rate and 83% workers utilization was realized. The shows how to make improvement on customers satisfaction. In this project we used the simulation model to measure the performance of the network.

2.2.3 OPERATIONAL MODELING

Operational modelling is technique is used in modelling the flow of an operational process. The model takes a form of input, process and output of a system. Kristensen (2002) modelled activities of a business process in a Military organization. The organization takes the form of Standard Operating Procedures (SOP). The activities consist of atomic unit in JMAP (Joint Military appreciation Process) planning process. The sum of the series of activities makes up steps for the planning process. An activity in the process depends on the information provided by the previous activities before it can commence operation. The operational process was modelled using Coloured PetriNets (CPN). The operational model that was developed is useful for the education of staff at the Deployable Joint Force Headquarters' (DJFHQ) Australia. DJFHQ is the joint headquarters' for the Army, Navy and Air force.

Ji & Gu (2006) used an operational modelling approach for minimizing the total operating costs of the closed-loop logistics in a company. The model has two important features. The first one is the end-customer's willingness to return used products to the company. An assumption that the amount of returned products is an increased function of the reclaiming price. Secondly the recoverable ratio through the uncertainty of quality of the used product is also taken into consideration. The model was compared with another model Model-II. And the numerical results revealed that the operational cost can be saved about \$10, 025,000 a year by using the developed (Model-I). The recoverable ratio increases and the amount of saved cost increases also.

Batraneanu et al. (2008) developed an operational model for the ATLAS TDAQ (Trigger and Data Acquisition (TDAQ) network. The network consists of four separate Ethernet based networks which together total over 4000 ports with 200 edge switches and 6 multi-blade chassis switches at the core. Despite the large number of switches on the network, a simulation model was not considered. However, tools were provided to automatically cross-check for consistency of the network installation. Operational statistics like the port status and throughput were continuously logged and made available to TDAQ control to measure the performance of the network.

An operational model was developed by Jemenez et al. (2002) for the inter bay AMHS (Automated Material Handling System) in semiconductors. The system has stockers that are located in a two floor layout. The operational logic of the AMHS was followed in the design of the model. The model reflects the movements of automated devices moving lots between the stockers or from one layer to another. The goal is to select devices that make delivery of

the lots to the respective destination at minimal time. A simulation model was also developed to achieve the best performance. This further strengthens our use of simulation model in this study.

Cho (2002) use an operational modelling approach to model a clustered the network of a clustered radar system. The aimed was to provide high QoS real-time radar data to end-users. The operational model was supported by the current data network technology for the real-time clustered radar system operation. A network model and an end to end architecture were also developed. TCP SACK and RED queuing scheme was discovered to perform better for the fair distribution of the bottleneck bandwidth among all connections without background traffic. The fairness of bottleneck bandwidth was also improved with randomized background traffic. Simulations were made and the result shows that the fairness would not become a critical issue for the network model. The analysis of the model assisted the authors to reach a conclusion that the network architecture could be practically deployed. And the attained network throughput by the RTT shows that the MEO and LEO satellite link will not demand data compression after deployment. The predicted performance is under steady state.

Chen (2002) designed an effective new Resource Reservation Protocol /Common Open Policy Service (RSVP/COPS) signalling operational model to support the delivery of end-to-end QoS across IntServ network and DiffServ domain. The RSVP (ReSerVation Protocol) is a signalling protocol defined by IETF (Internet Engineering TaskForce). The end to end RSVP messages are to be transported to the DiffServe domain. Because of the complexities involved in the communication an admission control algorithm was developed in this model for Bandwidth Broker to check QoS parameters when communicating with routers and to

dynamically provide resources provisioning for DiffServ domain and to make available a dynamic resources provisioning for DiffServ domain. Statistical methods were applied to analyze the typical DiffServ operations and to compute the probability of directional Internet flow moving from one router to another. Simulations were made and the result shows that the model can provide lower setup time than others models which employs complicated signalling protocol and distributed message handling mechanism.

2.3 LAN PERFORMANCE MODELING

Many research work done on performance of a network have to model the traffic on the network. In order to model a LAN, it is important to know the packet object and profile configuration of the network. Some LAN might be modelled into a single node and it important to specify the utilization that fluctuates over time on a link. Simulation of scenarios and analysis are to be considered lastly in modelling a LAN.

Fitzgerald & Harper (2008) did a study on the application of simulation modelling for Air Force Enterprise IT transformation initiatives. This was done to mitigate the risk within the department of defense's enterprise IT system to optimize Enterprise IT architecture design, so as to meet the needs of operational end users. A model was built to examine the impact of the Air Force's Service Delivery Point (SDP) capacity on ERP (Enterprise Relational Platform) end user delivery. An SDP is a combination of routers, switches, and firewalls. The SDP at each base serves to connect the base Local Area Network (LAN) to the Air Force's Wide Area Network (WAN). Information Packets move from a location X to Y. The objective of

the model was to examine the current and future ERP end user response time. And the correlated infrastructure utilization for varying levels of SDP capacity. The study was useful to measure the performance of the ERP on the Network and to determine the utilization of the system for end-user.

Sadiki & Paimblanc (2009) developed a LAN model for spatial registration patterns of mobile users as the users move within a wireless local area network (WLAN). The model was based on the standard Opnet models for WLAN nodes. Extensive experimental data from a TeSA Labs 2.4 GHz WiFi LAN installation was used as the operational data. The authors divided the empirical data available into training and test data sets, developed the model based on the training set, and evaluated it against the test set. The study shows that the model can be very useful for studies of the performance of mobile wireless systems. Issues such as resource management and mobility management protocol can be addressed when the performance of such model is measured.

Virendra, Upadhyaya, & Wang (2004) proposed a low cost and generic secure wireless local area network (GSWLAN) model. The model which can be implemented on WLANs that comprises of access points (AP) from different vendors. The proposed model comprises of a WLAN with wireless nodes and access points, which are connected to the distribution system through a router. The admission controller (AC) and global monitor (GM) are two additional nodes on the distribution system. The AC's role is to allow or disallow a new wireless node to enter the network. The GSWLAN model maintains trust levels and associated these levels with the decisions to allow or disallow a node to perform certain operations. There are three trust levels in the model: Low/Unknown, Medium and High. Only the nodes with high trust

value can perform an operation whose result might have a critical impact on the health and functioning of the network. The model was validated by sending DOS attack to a node on the network, and simulations show that the model ensures network survivability in the event of a denial of service (DOS) attack with minimal throughput degradation.

A local area network (LAN) model with regards to problems of digital device technical diagnosis was proposed by Hahanov, Babich & Halil (2001). The problems are fault simulation, test generation and default search. Existing methods and algorithms of digital devices were used. The authors represented the computer network for the users as a computer with virtual representation on the screen of information. The network was represented with a two dimensional model of a personal computer (PC) as hardware while the software is represented as the third dimension. The model creation is brought to execution by representing the LAN as a graph and testability analysis of the network using Boolean equation. The model efficiency of the LAN model was tested on about two hundred (200) workstation. Modifications were made on the methods and algorithms of digital devices and the problems were tested for minimization of timing expenditure at diagnosing procedure executions.

Burmeister et al. (2006) developed a rate adaptive analytical wireless local area network (WLAN) model and extended it to model several TCP down-link connections. The authors modelled the access point as an $M/G/1/B$ queuing system and derived the arrival rate and service time distribution from the analytical WLAN model. Queuing system was solved by the authors for the model's sojourn time and loss probability. The standard TCP model was used to arrive at a set of non-linear equations for the throughput of each user on the network,

where the throughput depends on round trip time (RTT) and loss probability. The solution to the non-linear equation made it possible for the authors to calculate the expected TCP throughput of each user in several scenarios with different user distributions. The results of the model were validated by simulations.

Zaitsev (2005) modelled a sample Local Area Network with coloured Petri net. The model consists of places, drawn with different shapes as circles (ellipses), transitions, bars, and arcs. The dynamic elements of the model were represented by tokens, and a detailed representation of the real network was derived. The response time of the servers to the clients were measured.

2.4 SIMULATION TOOLS

The specific simulation tools are used for specific simulation such as network simulations. Some of the available tools are listed by Orfanus et al. (2008) as Omnet++ ,Ns2, ShoX, Jsim. Others are cnet, GlomoSim, GTNets, NCTuns, Netsim, Opnet, optsim, PERSEC, Performance Prophet, Qualnet Developer, Shunra Virtual enterprise , traffic etc . Some new tools which are recently developed are HIT, HiQPN-Tool (which supports the analysis of hierarchical QPN models, a superset of Coloured GSPNs and Queueing Networks), DSPNexpress, APNN-Toolbox (Sztrik & Kim, 2006). Another specific simulator is QNAP which is used for manufacturing.

The general simulation tools are Arena, Matlab, Ilog etc. This serves as a multipurpose simulator. A good number of these simulation tools are open source. The developers of these simulation tools reserved these versions for research purpose while some versions are proprietary.

2.5 SUMMARY

The use of a simulation tool is advantageous because of its flexibility. But there could be some hard time. The programming language construct can be used to achieve new modules. The limitation is that it might take quite a long modelling time with high programming skills. Using a simulator with inbuilt modules takes lesser time to complete. The problem arises when there is need for a functionality that is not in the module. Then there will be a need to add the programming functionality. The complexity of a simulation model will depend on the detail of our representations of the timing behaviour of the system operation. But this can be avoided by making the right choice of a simulation package.

CHAPTER THREE

OMNET++, THE DISCRETE EVENT SIMULATION SYSTEM and UUM LAN

3.1 INTRODUCTION

Omnet ++ simulator was used to develop the simulation model in this study. This chapter gives a brief presentation of the main features of OMNet++ used in developing the network model. The current Local Area Network features and its connection are also discussed.

3.2 MODELLING IN OMNET++

OMNet++ (Vargas, 2008) is a discrete event simulator that is written with C++, it is a well structured and scalable simulator with high modularity. The simulator allows modules to exchange messages. Omnet++ is an acronym of Objective Modular Network Testbed in C++. OMNet ++ is an Open source simulation system, therefore it can be freely used by the academia for research purposes. All it takes is to download and install the OMNet engine and frameworks from its website .The simulator can work and run freely on the Windows, UNIX and Linux Operating systems environments.

A basic OMNet model usually consists of modules that can connected to each other in an hierarchical order. The modules communicate to each other by passing messages to each other in order to form a network. The modules that host other modules are referred to as the system

module. The system modules have Compound modules which also contains simple modules (Figure1). The nesting of the modules is not limited so as to allow users to reflect the logical structure of the actual system that is been modelled.

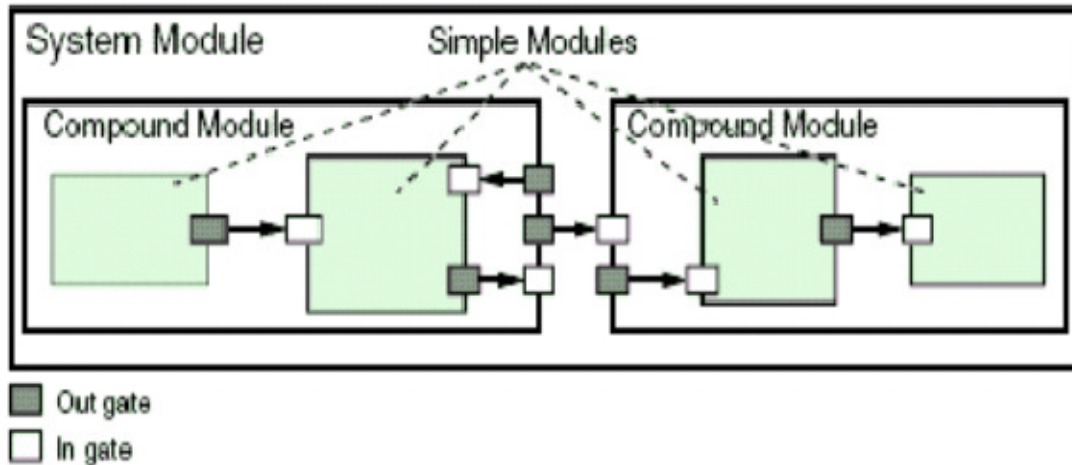


Figure 2: Hierarchy of Modules in OMNeT++ (Vargas, 2005).

OMNet has a NED language which is used to describe the OMNet model structure. The NED language is simplified and easy to understand and write. There are Compound modules which host submodules and also there are simple modules which are the least of the modules that can be constructed with the NED language. There are algorithms that are included in the simple modules of the model. This simple model is implemented by the user in C++. This is made possible by the OMNet simulation library. During simulation packets, jobs or customer is represented by messages in a computer network, mobile and queuing networks etc.

3.2.1 OMNET MODULES CONNECTION

The simulation time of a module is triggered when it receives a message. This depends on the source of the message as a module can even generate messages to set time. Each module contains interfaces called gates. There are input and output gates. Connections between modules are made possible through the interfaces. The connections are (full duplex) one way in opposite direction. Messages come in to a module through the input gate and leave the module through the output gate.

It is noted that hierarchical structure of the model affects the journey of the message. This is such that the message will have to travel through series of connections to and fro the modules. When there is a connection between simple modules it is called routes. While the compound modules relate messages between the modules they contain and the outside world in a transparent manner, a click on the module during simulation will reveal this.

In order to make connections between modules, there are three parameters that need to be set which are propagation delay, bit error rate and data rate. For smooth connectivity when the mac- transmission rate is set then the data rate should be turned off or this will generate error message during simulation initialization. Although the parameters are optional, link parameters can be set individually for each connection, or make a definition of link types so as to use throughout the model.

All the simple modules contain algorithms with C++ functions. A simulation programmer has the opportunity to use object-oriented principles (inheritance, polymorphism etc.) and design patterns to extend the functionality of the simulator.

3.2.2 OMNET++ MODEL COMPONENTS

A typical model in Omnet++ consist of the following

1. NED language description of the topology.
2. Definition of messages.
3. Implementation of simple modules and C++ codes to use for execution.

In order to build a running simulation program, the user needs to translate the configured NED files into C++. The NED compiler which is called the NED tool and the message compiler known as the opp msgc assist in performing this operation. The compilation of the simulation is similar to building C or C++ program from it source. Most often time than not in many simulations, the performance of the system after it has reached a stable state (steady state) is of interest. The beginning of the system is called the transient period. The simulation will have to run until the model reaches a steady state condition. In this project work we ran our simulation well beyond the transient state. This is because it is important to run simulations until enough statistical data has been gathered for computation of result with the needed accuracy.

3.3 UUM LOCAL AREA NETWORK

In 1990 the UUM computer centre implemented the campus communication network using the single mode fibre optics. The Integrated Sintok Local area Network (ISLAN) project later commenced to upgrade it to ATM technology. The purpose of which is to increase the usage of the University IT as a strategy to increase education, learning, research and development (R&D). The project was completed in February 1996 making the university a wired

university. Staffs and students and other users can get data/information from any wired building on campus.

The network was further increased from ATM technology to 1gigabit technology in 2000, integrated with data, sound and video. The LAN was further upgraded from 1 GB to 10 GB in the year 2008, as expansion has been made by adding more nodes to the network and the network is growing. The Internet bandwidth was also increased from 45Mbps to 155Mbps. Most of the upgrades are capital intensive costing millions of Ringgits. A Network Operation Centre (NOC) Unit was created to monitor the performance of the network as Denial of Service (DoS) is experienced at some quarters and users complained of slow network connection. The network is been managed by the Network Operation centre (NOC). The centre manages both the wired LAN and Wireless LAN. Both of which are independent of each other. There are currently more than 70 wireless Access points and base station networks on the campus. This makes it possible to have hotspots round the university campus.

3.3.1 THE LAN STRUCTURE

The wired LAN supports the connectivity of several units and sections of the institution to IT facilities and services provided by the Computer Centre. The network currently uses gigabit technology. The network is a star topology with 3tiers, it is characterized by the user nodes, the access/edge switches, the distribution switches and the Core switches. Refer to Appendix B.

3.3.1.1 CORE SWITCHES

There are two Core switches on the network. The two switches has the same configuration; one of the switches is for redundancy. The Centre choose to reserve a switch for redundancy, in a case where the main core switch goes down the distributing switches gets connection from the other core switch. The Terminal switches in the various block on the campus depends on the Distributive switches for connectivity.

3.3.1.2 THE DISTRIBUTION SWITCHES

The switches are arranged such that a breakdown in any of the switches will only affect the section of terminal switch which is connected to it. Currently there are about 250 Cisco catalyst switches are connected on the network.

The type I switch Series has modular centralized architecture, it is expandable with the ability to control the network edge switches intelligently with six (six slots). And the capacity to deliver about 136 Gbps of Layer 2–4 switching. It possesses set of line cards to provide port about 384 10/100 or 10/100/1000 ports using integrated Power over Ethernet (PoE). This type of distribution switch also provides 10 Gigabit Ethernet (10GbE) uplink ports for high density Gigabit Ethernet-to-the-desk as well as switch-to-switch applications. This switch is connected directly to the core switch and it controls quite a number of distribution switches. The switch is connected to the Core Switch.

The Type 2 switches have the Same Architecture as type 1 but with different specification. It is expandable with the ability to control the network edge switches . The switches Combines 10/100/1000 and Power over Ethernet (PoE) configurations with up gradable 1 Gigabit

Ethernet to 10 Gigabit Ethernet (10GbE) uplinks, it supports IP telephony, wireless, and video. With 48 ports Additional 10/100, 10/100/100, 10 Gigabit Ethernet (10GbE), and Power over Ethernet (PoE) connectivity. The switches are expandable for upgrade. It features IP Unicast and IP Multicast routing as well as Policy-based Routing (PBR).

3.3.1.3 EDGE SWITCHES

VLAN was configured on all the switches in order to control user's access and control unauthorized accessibility. The EDGE SWITCHES uses both Fast Ethernet and Gigabit Ethernet desktop connectivity. The switches are compact silent models are ideal for office, lecture rooms and any other. The switches are typical layer two switches with the capability of creating VLAN and access control lists (ACLs). Spanning Tree Protocol is another feature of the switch configured for alternative wired uplinks for Gigabit Ethernet. This makes room for fibre optics uplink. Using 10/100/1000 port and one SFP-based port, with one active at a time. This reflects in our model that only one uplink is active. The switches consist of 24 Gigabit Ethernet port which drive effective Gigabit to the Desktop (GTTD) across the network.

3.3.1.4 USERS NODE

There are about 66 computer laboratories in University of Utara Malaysia. Students and staffs have access to the computers for computational works and research. Most of the computer labs are located at the faculty buildings and students residential buildings. The user's pc in

population is about 2430 PCs. The computers have the following configurations. Processor: Pentium III 450 Ghz, Pentium IV 1.8 Ghz, Pentium IV 2.4 Ghz. Memory : 64MB, 256MB, 256MB and HardDisk of 10GB, 20GB and 40GB respectively.

3.3.1.5 CABLES

The cabling system is a backbone to connect between the buildings by using fibre optics cables. Both single mode and multiple modes are used on the network. The single mode fibre optic is the functional link in the network. It has a single strand of fibre with about 8 to 10 micron in diameter. The cable is the main channel between all the switches on the network for both uplink and downlink. It also has smaller core to the multimode. The function of the small core is to remove distortion that may result in light pulses. This makes the link to provide minimal attenuation and deliver needed transmission speeds of the cable type. The multiple mode fibre cables are used as a backup link on the network. Multi-Mode cable has a bigger diameter compared to the single mode. Multimode fibre has the capacity to deliver high bandwidth at high speeds from 10 to 100MBS – Gigabit. This can cover from 275m to 2km. This covers medium distances between the faculty buildings and the Computer centre and The Library where the core switches are located.

The Ethernet cabling system connects the computers to the switches using the UTP Technology (Unshielded Twisted Pair) cat 6 which has a speed of 1Gb. The cat 6 cables are used to connect the user nodes to the access switches. These are LH/SX 1000 BASE-T (Gigabit Ethernet). While the cat 5 cables are used to connect the firewall and the Router and

some user nodes on the network. The cables are Unshielded Twisted Pair (UTP) with 10/100 BASE-T.

3.3.1.6 ROUTER

The router breaks down the collision domain on the network. The major role of the router is to segment the network. This is done in the section by separation the internal network from the external network.

3.3.1.7 FIREWALL

The firewall stands as a security mechanism to the network. It is positioned behind the router to filter unauthorised access in to the UUM network from the external network. Any dangerous packet that passes through the gateway, the firewall will drop the packet as it is hazardous to the data kept on the data servers on the network.

3.3.1.8 SERVERS AT THE DATA CENTRE

There are two physical servers located at the data centre (refer to Appendix B). The server 1 & 2 are HP servers and running on Unix/Linux operating system. The two servers represent the pool of servers as virtualization is configured on the servers using VMware. The other two servers are located at UUM city campus in Kuala Lumpur for backup and data recovery.

3.3.2 OPERATION AND CONNECTIONS ON THE NETWORK

The movement of data packets is such that it path is to and fro from the user nodes through the edge switches to the distribution switches and passing through the core switches to the

data centre and internet. The structure of the network is in three layers (3tiers) in the UUM network. The distribution (type I&II) switches are connected to the two core switches which lie in the middle of the network; these are the major switches on the network. Both switches has the same configuration on them, one is used for redundancy. In the event of a break down in one the other will assume its duty. The edge switches at the designated buildings are connected to the distribution switches. This is the points where students and staffs have accessibility to the network resources i.e. Computer laboratories, lecture rooms and staff offices.

3.4 SUMMARY

Omnet++ is the best simulator to be selected in simulating the situation on a computer network. This is as a result of the in built modules that measures parameters in packets, bytes and seconds. Also these modules can effortlessly be configured to mimic the situation of a real computer network. The topology of the UUM networks gives the current scenario of packet switching on the network and the hardware that are of use on the network. The IT equipments used on the network is up to date as a result of constant upgrade.

CHAPTER FOUR

MODEL DEVELOPMENT AND VALIDATION

4.1 INTRODUCTION

This chapter explains how the simulation model was built, and the reason for our choice of simulation tool. After an appropriate the network event simulator was selected, the model was designed and built from the available data collected from the institute's computer centre.

4.2 THE SIMULATION MODEL

In order to build the simulation model, it is of importance to select an appropriate network event simulator. Omnet ++ was selected because its ease of use, extensibility with modular object oriented approach (Riley, 2003; Vargas, 1999; and Kogekar et al., 2006). Omnet is an Open Source event simulator which can be downloaded from its website (Vargas, 1999). There are quite a number of compiled models to build related networks with. This is called INET/ Mobility Framework; there is no need to develop codes for modules unless the needed model is not included in the frame work. Nevertheless the modular integration and Omnet++ initialization configuration is of paramount importance.

Modules were created for the firewall, router and for each of the switches, servers and clients on the network. The non redundant connections were of importance in the model. The switch was modelled using the Ethernet switch, a module that is incorporated in the INET Framework of the OMNet++. The module has a relay, a simple module that is embedded in the switch. The definition of the mac relay unit was recorded in the omnet.ini file. The switch also has an Ether Mac layer that performs transmission and reception of frames.

The router and firewall was built by using also an inbuilt module in the INET-Framework. The clients and servers on the network were also developed using inbuilt modules Ethernet host (EtherHost), which also has inbuilt simple modules logical link control (EtherLLC). The EtherLLC processes commands received from upper layer of the network. The EtherHost also consist of the client and the server sub-modules .The server sub-module receive data-packets as it was configured as a server while the client sub-module generates self messages as it is configured as a client.

The transmission rate was set for the hardware using the channel module and setting other transmission rate at the omnet.ini file. It is assumed that the initial processing time on the switches and servers at the data centre is 0.2 second. The initial arrival rate of data packets is assumed to be 2/s, as these operational data were not available at the centre. Snapshots of the developed simulation model are presented in Figure 3 to Figure 8.

Figure 3 displays the computer centre, Faculty of Economics, and the data centre on the simulation model.

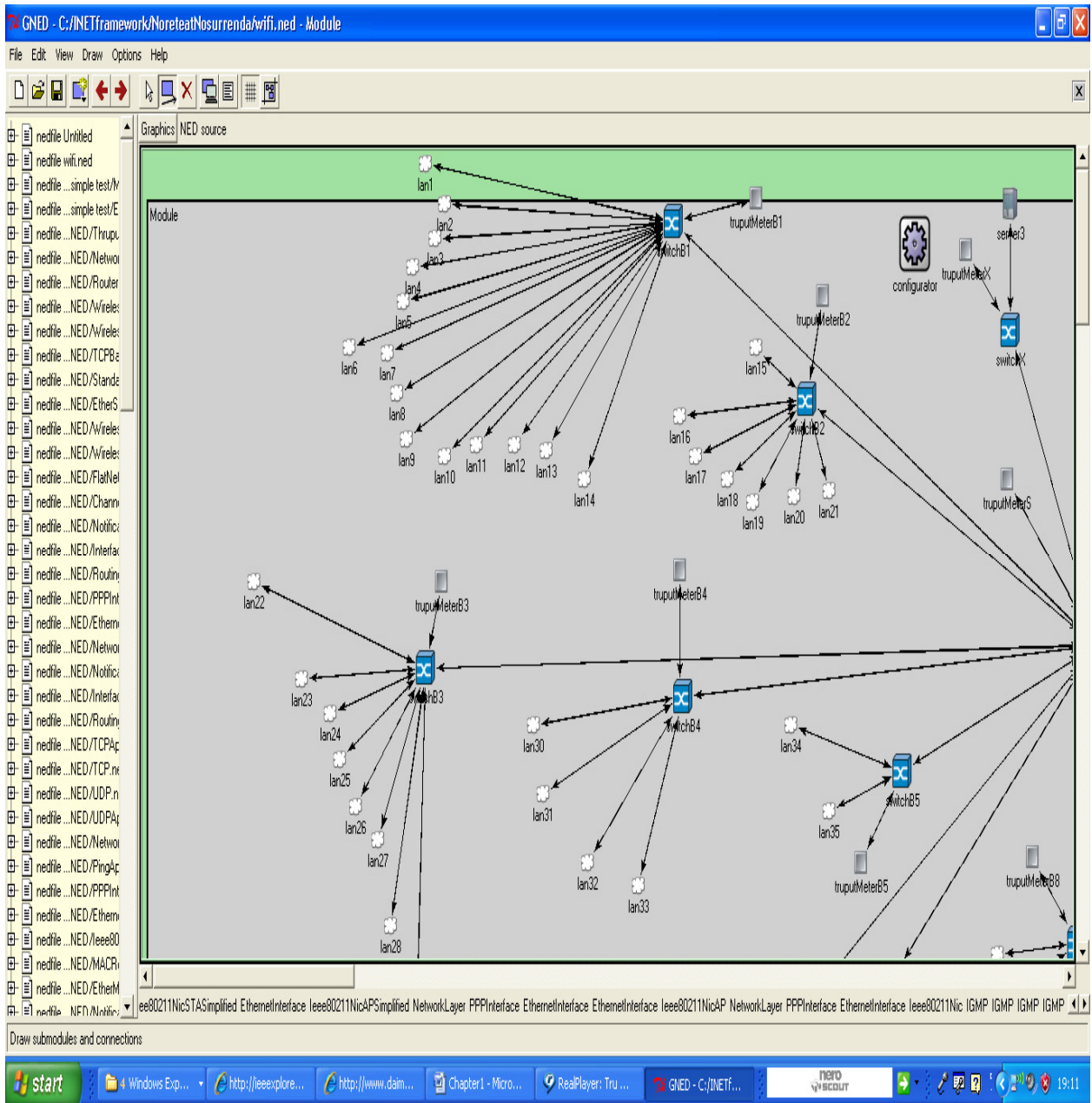


Figure 3: A Snapshot the Computer Centre, Faculty of Economics and the Data Centre on the Simulation Model

Figure 4 displays the core switch, the distribution switch at the data centre and the distribution switch, firewall and gateway to the internet. While Figure 5 displays the, Kolej Eon, Palapes, PKP and the convention centre on the model.

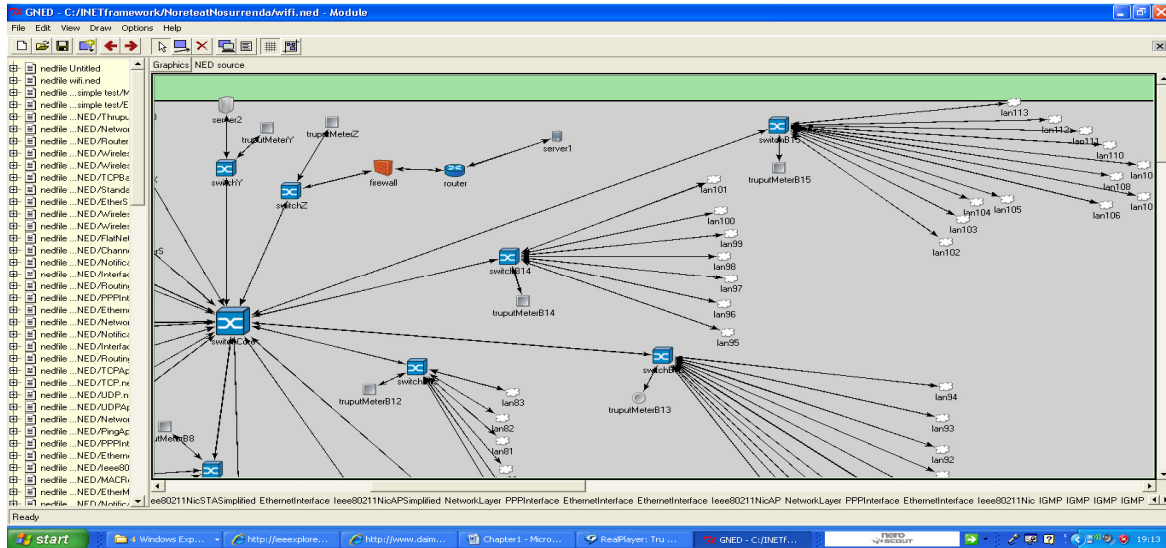


Figure 4: A Snapshot of the Data Centre, gateway to the Internet and FTM on the Simulation Model

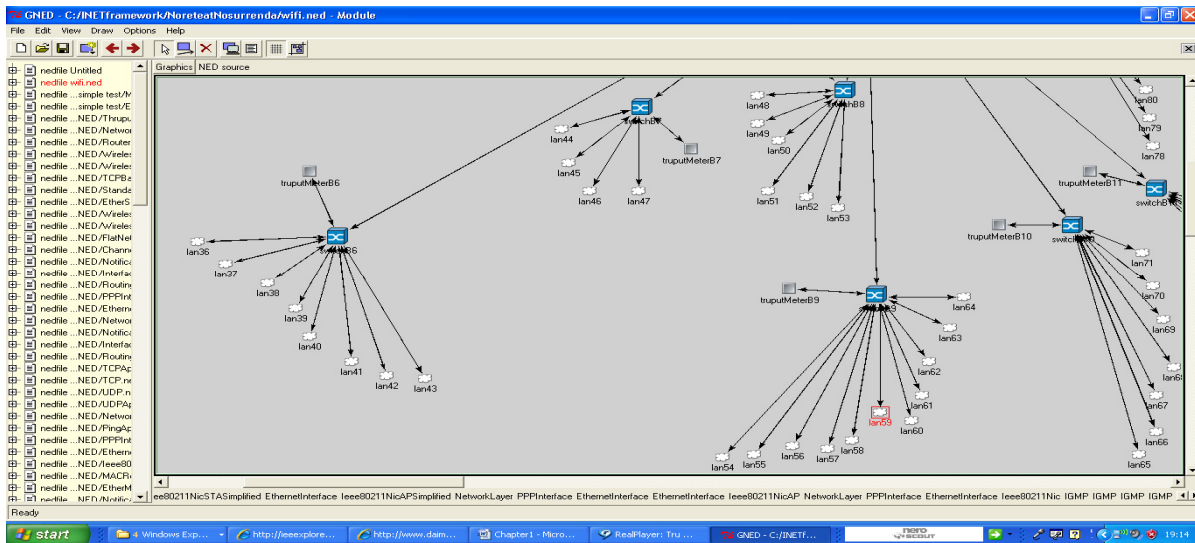


Figure 5: A Snapshot of Convention Centre, Kolej Eon, Palapes, PKP on the Simulation Model

Figure 6 displays the distribution switch in Bukit Kachi, FSK, FWB and FPK on the Simulation Model while Figure 7 displays 12 user computers connected to an access switch.

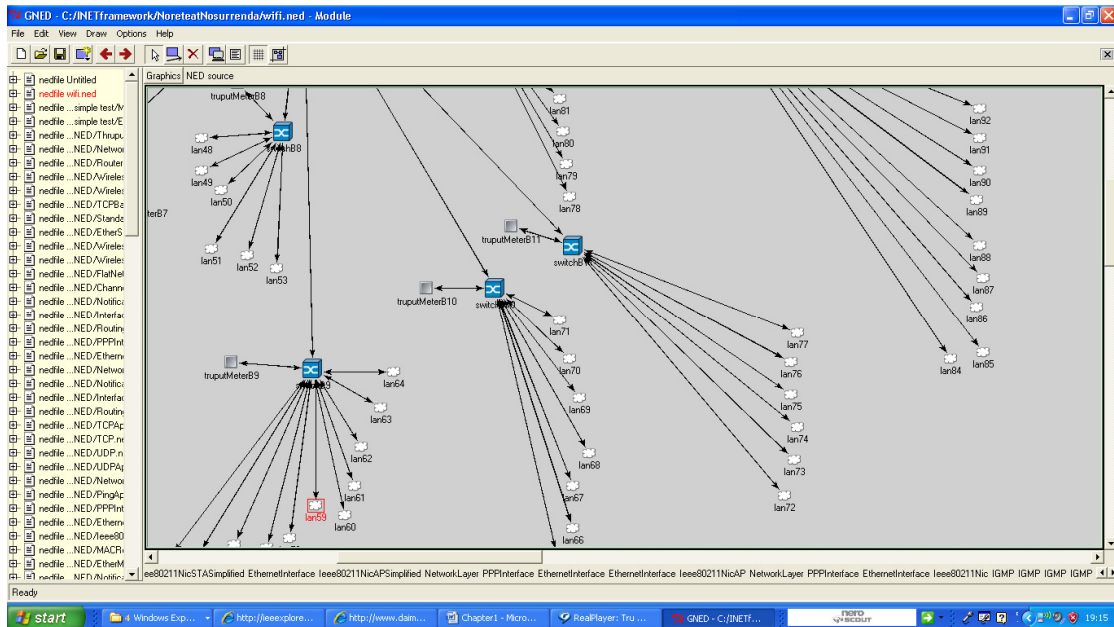


Figure 6: A snapshot of Bukit Kachi, FSK, FWB and FPK on the Simulation Model

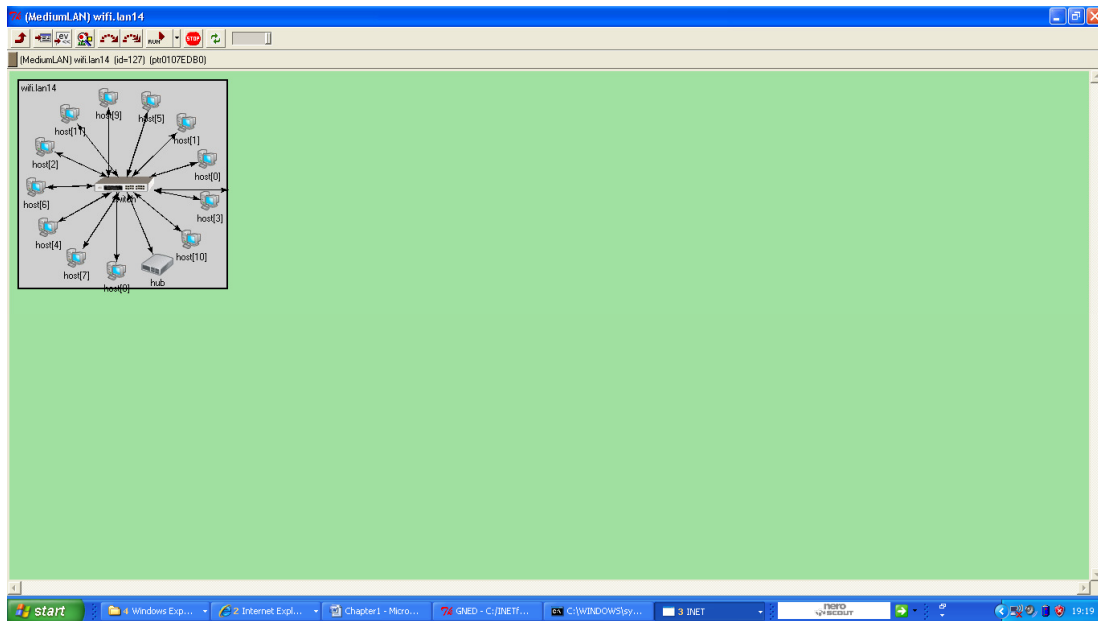


Figure 7: A snapshot of 12 user nodes on a switch in the Simulation Model

Figure 8 displays an increased number user computers from 12 in Figure 7 to 23, the computers can be seen connected to an edge switch.

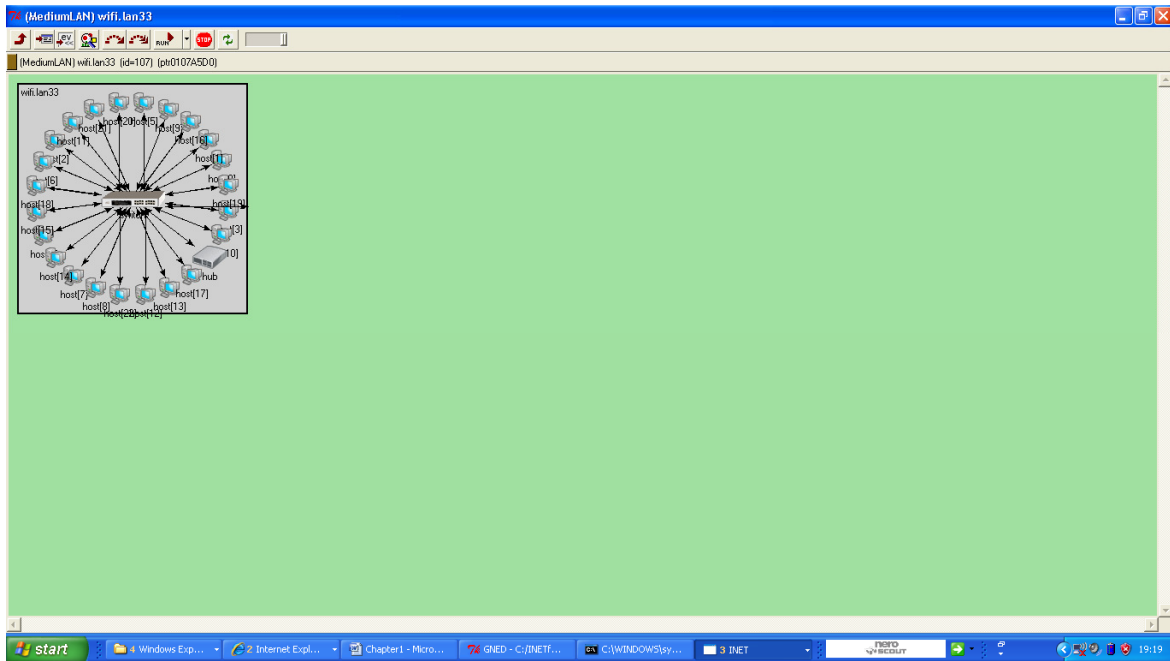


Figure 8: A snapshot of 23 user nodes on a switch in the Simulation Model

4.3 MODEL VALIDATION

The process of verifying whether the simulation model is an accurate representation of the real system is model validation (Law & McComas, 2001). This is needed to fulfil the objective of the study. Therefore the collected data should be accurate. The logical connection and the use of accessible and appropriate data are used to validate the simulation model in this study. The hardware specifications were configured in the model: the buffer memory of the switches, channel data transmission rate along with the corresponding number of computers attached to the access switches on the network. The first simulation run was made and a subsequent time study of the data packet acknowledgment to the internet and servers at the data centre was made. The collected round trip time (RTT) was used to assume

the processing time. From the collated result from the study in Table 1 it can be assumed that the model can be used to represent the real network. The percentage difference of the first packet acknowledgment (RTT) is stated below.

$$\text{Error \%} = 100(\text{Model Ack} - \text{Actual Ack}) / \text{Model Ack}$$

Table 1: A Comparison of the Actual and Model Acknowledgement

System	Processing Time(s)	Model RTT(ms)	Actual RTT (ms)	Error %
Internet	0.2	5.45	5	8.25
Server1	0.2	1.201	1	16.74
Server2	0.2	1.208	1	17.22

4.4 SUMMARY

The important step to ensure that the developed model returns accurate results is dependent highly on the validation. The validation of the model of the study was made by the use of accurate data rate, memory capacity of the switches and a time study of the RTT/acknowledgement.

CHAPTER FIVE

SIMULATION RESULTS

5.1 INTRODUCTION

This chapter describes the experimental use of the simulation model in predicting the future behaviour of the network. The experimental design is described in the next section, while what if scenarios (variations) are presented in section 5.3. Section 5.4-7 includes the write up on the effects of the selected performance metrics, when several parameter values are changed.

5.2 EXPERIMENTAL DESIGN

The experiment was performed by running simulation using the initial parameters in Table 2. Variations were made by increasing the processing time on the internet, switches and servers on the network from 0.2s to 0.1s in a range of 0.2, while the initial parameters were kept constant. Furthermore, variations were made by increasing the packets arrival rate from 2/s to 10/s in a range of 2, while other initial parameters were still kept constant.

Table 2: The Initial Parameters and Symbols

Parameter/Symbol	Initial Value
Internet Process time (S)	0.2s
Server1 Process time (S)	0.2s
Server2 Process time (S)	0.2s
Internet Link Speed	155Mbps
Server1 Link Speed	100Mbps
Server2 Link Speed	100Mbps
Internet No of Nodes (N)	1100
Server 2 No of Nodes (N)	700
Server 3 No of Nodes (N)	200
Arrival rate (λ)	2packets/s
Simulation Time (T)	1000s
Throughput (γ)	0
Utilization (U)	0

5.3 VARIATION IN THE PROCESS TIME

The first experiment was performed using a varied number of users as shown in Table 2 to test the behaviour of the parameters on the throughput and end to end delay. The service time of switches and servers on the network were varied to know the impact on the throughput. The results can be seen in the Table 3 below.

Table 3: The Process Time against the Internet, Server1 and Server2 Throughputs.

Throughput pck/s	Initial χ	χ^1	χ^2	χ^3	χ^4
Internet	0.862	0.413	0.277	0.221	0.164
Server1	1317	0.646	0.424	0.349	0.282
Server2	0.639	0.318	0.220	0.121	0.077
<i>Processing time</i>	<i>0.2</i>	<i>0.4</i>	<i>0.6</i>	<i>0.8</i>	<i>1.0</i>

5.3.1 EFFECT ON THROUGHPUT

The variation of the process time has a significant impact on the throughput. It can be noticed from Figure 9 that as the process time increases, the throughput for the internet and the servers' decreases. There was a sharp decrease for the first variation. The three thick lines in the graph below represent the internet, server 1 and 2 which are the servers at the data centre. The corresponding throughputs on the servers were plotted against the varied processing time on the server and the internet.

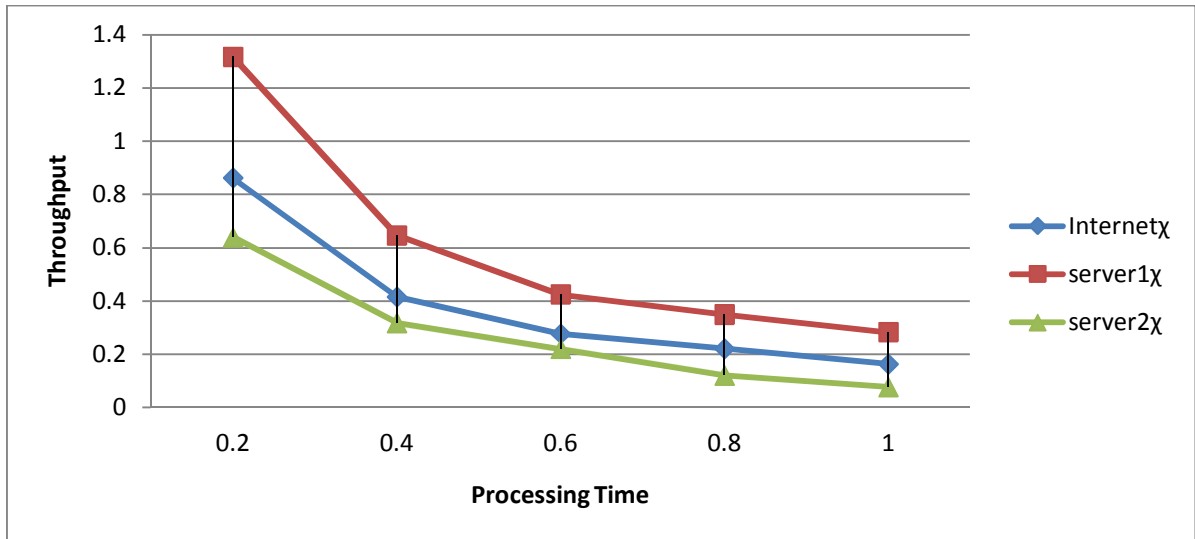


Figure 9: The graph of the process time on against the Internet, Server1 & 3 throughputs.

The graph above shows that server 1 has the highest throughput for the first simulation and subsequent simulation. This is as a result of the channel bandwidth of 10 gigabits from the core switch to the server switch (see Appendix B), and the number of users nodes (700) accessing the server. Server 2 has the lowest throughput throughout the experiment despite the small number of user nodes (200) accessing it. The effect of other factors such as number of user nodes and the arrival rates is further investigated in section 5.4 to section 5.7.

Figure 10 displays the graph of the throughput on all the distribution switches on the network. Each line represents a distribution switch in the model. Figure 10 also displays the throughputs against the varied processing time on the switches. There is also a significant impact of the varied processing time on the throughput on the distribution switches on the network. Figure10 shows decrease in the throughput (χ) as the service time increases. This shows the great impart the processing time has on the throughput on the network.

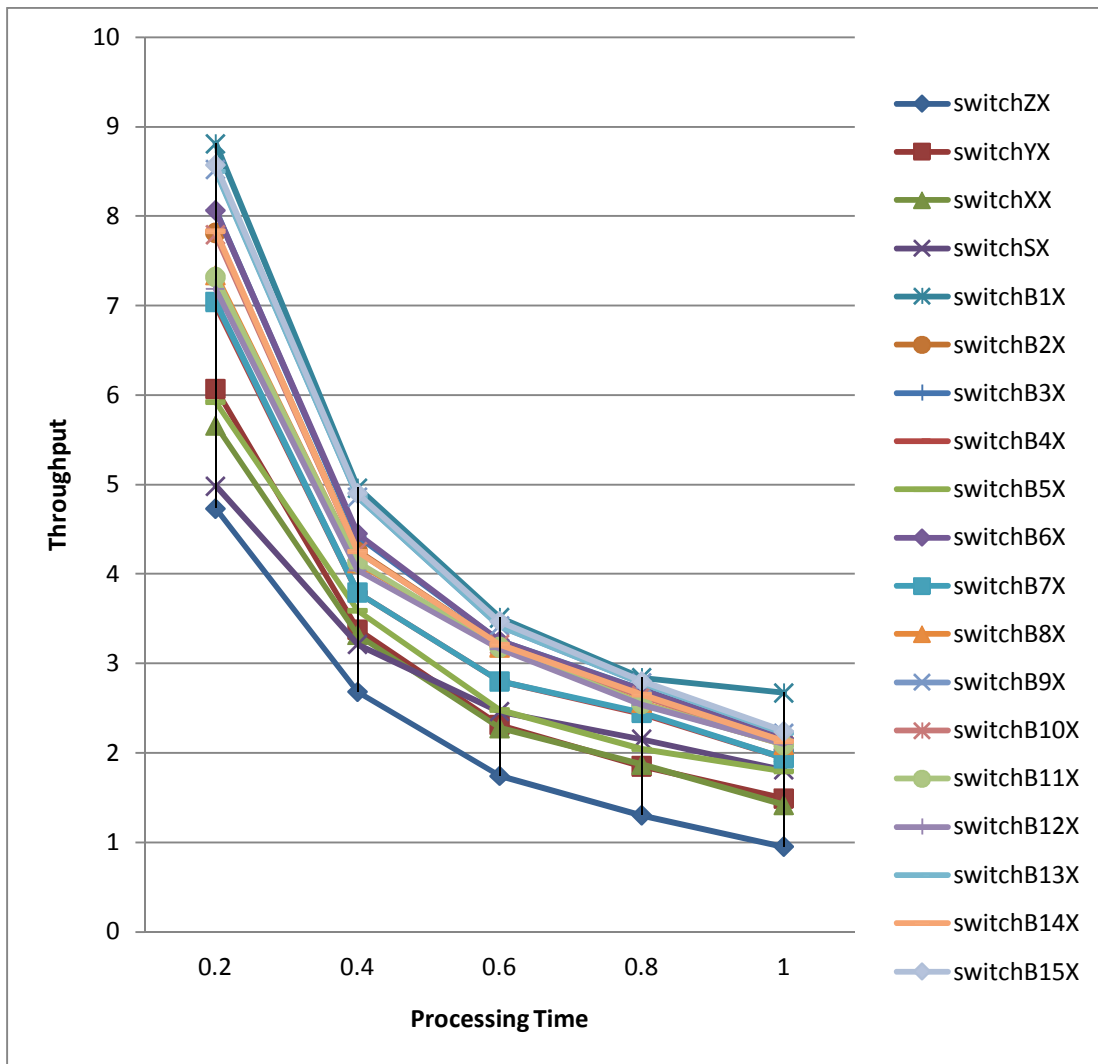


Figure 10: The Graph of the Process Time against the Throughputs on the Distribution Switches.

Any packet with the destination of internet and the servers at the data centre must pass through the switch S which is the core switch. This explains the reason for its low throughput. The internet switch, switch Z has the lowest throughput throughout the experiment. This is because a high number of user nodes are accessing the internet. Other switches have different number of access/edge switches and user nodes connected to them (see Appendix B). Further investigation on the impact of the number of users is investigated in section 5.4 to section 5.7 using the data collected from the computer centre.

5.3.2 EFFECT ON THE END TO END DELAY

The service time variation also has notable impact on the end to end delay of data packets on the network. It can be noticed from Table 5.3 that as the process time increases the minimum end to end delay for of data packets to the internet and the data servers also increases. The Table below displays the recorded end to end delay on the network. The data packet delay on both servers at the data centre and the internet is recorded and is shown on the table.

Table 4: The Minimum End to End Delay and Process Time on the Internet and the Servers at the Data Centre

Processing Time	Internet	Server1	Server2
0.2	1.2	0.99	0.8
0.4	2.4	1.99	1.6
0.6	3.6	2.99	2.4
0.8	4.8	3.99	2.4
1	6	4.9	4

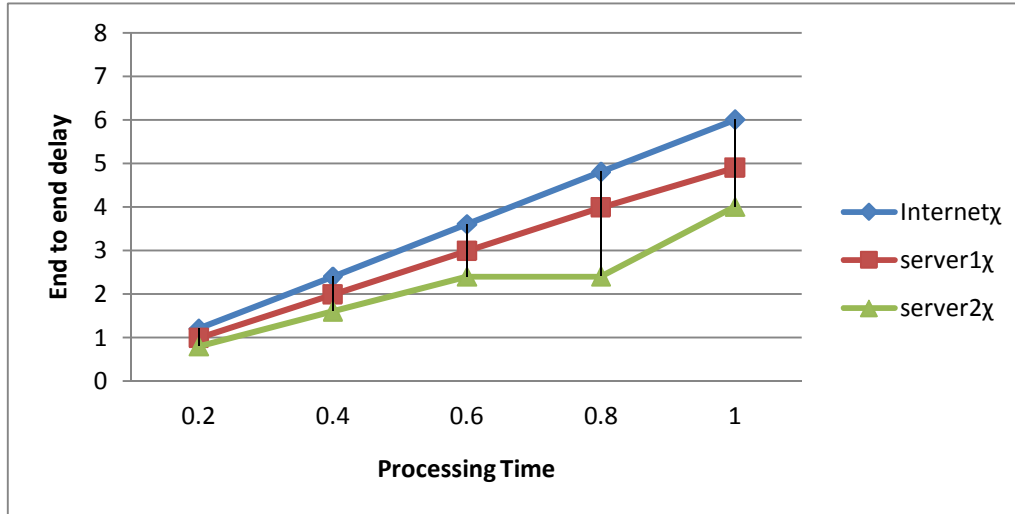


Figure 11: The Graph of the Process Time against the End to End Delay on the Network.

As displayed in Figure 11, each of the lines represents the trends of the reaction of the end to end delay to varied processing time in steps of 0.2s. It could be noticed that as the processing time increases the min delay time of packets to the data servers and the internet on the network also increases. This is a result of the increased processing time. Server 2 showed a stable delay at the processing time of 0.6 – 0.8s. This shall be further investigated in subsequent sections 5.4 – 5.7. Measurement of end to end delay on the network is important to a network engineer in order to know the reason for slow network connection at sections of a network.

5.4 VARIATIONS IN PROCESS TIME USING HALF OF THE NUMBER OF USER NODES

Half (1105) of the total numbers of user nodes in (Appendix C) on each LAN at the access/edge switches were used in this section. The simulation runs were made by sending packets to the internet and the servers at the data centre using equal number of user nodes.

5.4.1 EFFECT ON THE INTERNET AND SERVERS AT THE DATA CENTRE THROUGHPUT

Table 5 and Figure 12 displays the simulation results for the process time variations made on the internet and servers at the data centre.

Table 5: The Process Time and the Throughput on the Internet and the Servers

Processing Time	Internet χ	Server1 χ	Server2 χ
0.2	1.444	2.912	2.914
0.4	0.746	1.307	1.307
0.6	0.526	0.734	0.738
0.8	0.385	0.490	0.490
1.0	0.328	0.436	0.436

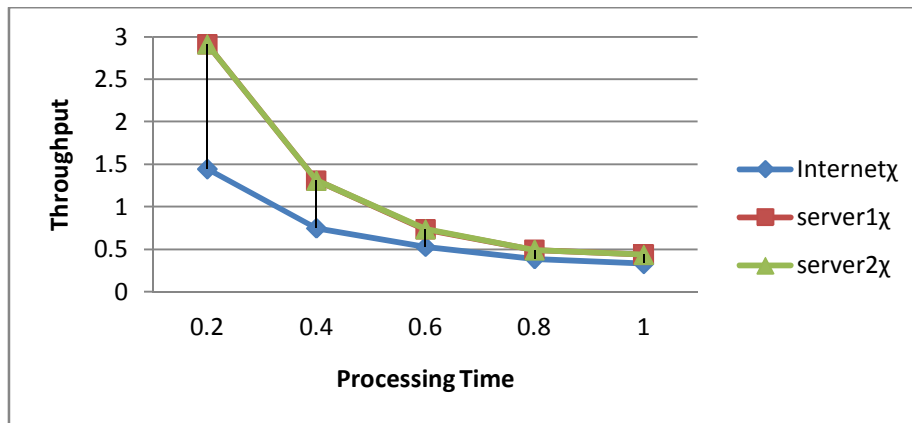


Figure 12: The Graph of the Process Time against Throughput on the Internet and Data Centre Servers.

The lowest throughput was recorded on the internet throughout the experiment in the above graph. The difference between the recorded throughputs on the servers at the data centre is insignificant. We shall further investigate the impact using the maximum user nodes in section 5.3

5.4.2 EFFECT ON DISTRIBUTION SWITCHES THROUGHPUT

Table 6: The Process Time and the Corresponding Throughput on the Switches

The measured throughput on the distribution switches					
Process Time	0.2	0.4	0.6	0.8	1
switchZ χ	3.027	1.72	1.096	0.716	0.472
switchY χ	5.728	3.156	2.289	1.996	1.562
switchX χ	5.718	3.156	2.285	1.966	1.562
switchS χ	3.113	2.083	1.858	1.847	1.559
switchB1 χ	8.149	4.953	3.451	2.790	2.230
switchB2 χ	5.013	3.183	3.116	2.541	2.028
switchB3 χ	7.190	4.820	3.368	2.721	2.174
switchB4 χ	4.885	3.295	3.082	2.508	1.996
switchB5 χ	4.313	3.295	2.040	1.859	1.554
switchB6 χ	4.387	3.295	2.930	2.457	1.960
switchB7 χ	6.059	3.295	3.326	2.690	2.148
switchB8 χ	4.560	3.295	2.352	2.288	1.834
switchB9 χ	7.046	3.295	3.393	2.745	2.194
switchB10 χ	8.434	3.295	3.479	2.813	2.250
switchB11 χ	4.972	3.295	2.850	2.535	2.023
switchB12 χ	6.308	3.295	3.289	2.659	2.123
switchB13 χ	9.031	3.295	3.564	2.877	2.303
switchB14 χ	4.789	3.295	3.077	2.504	1.995
switchB15 χ	8.169	3.295	3.453	2.792	2.233

Figure 13 displays the effect of process time as shown in Table 6 on the core switch and the distribution switches on the network. It could be noticed that switch B13 has the highest throughput while switch Z has the lowest throughput.

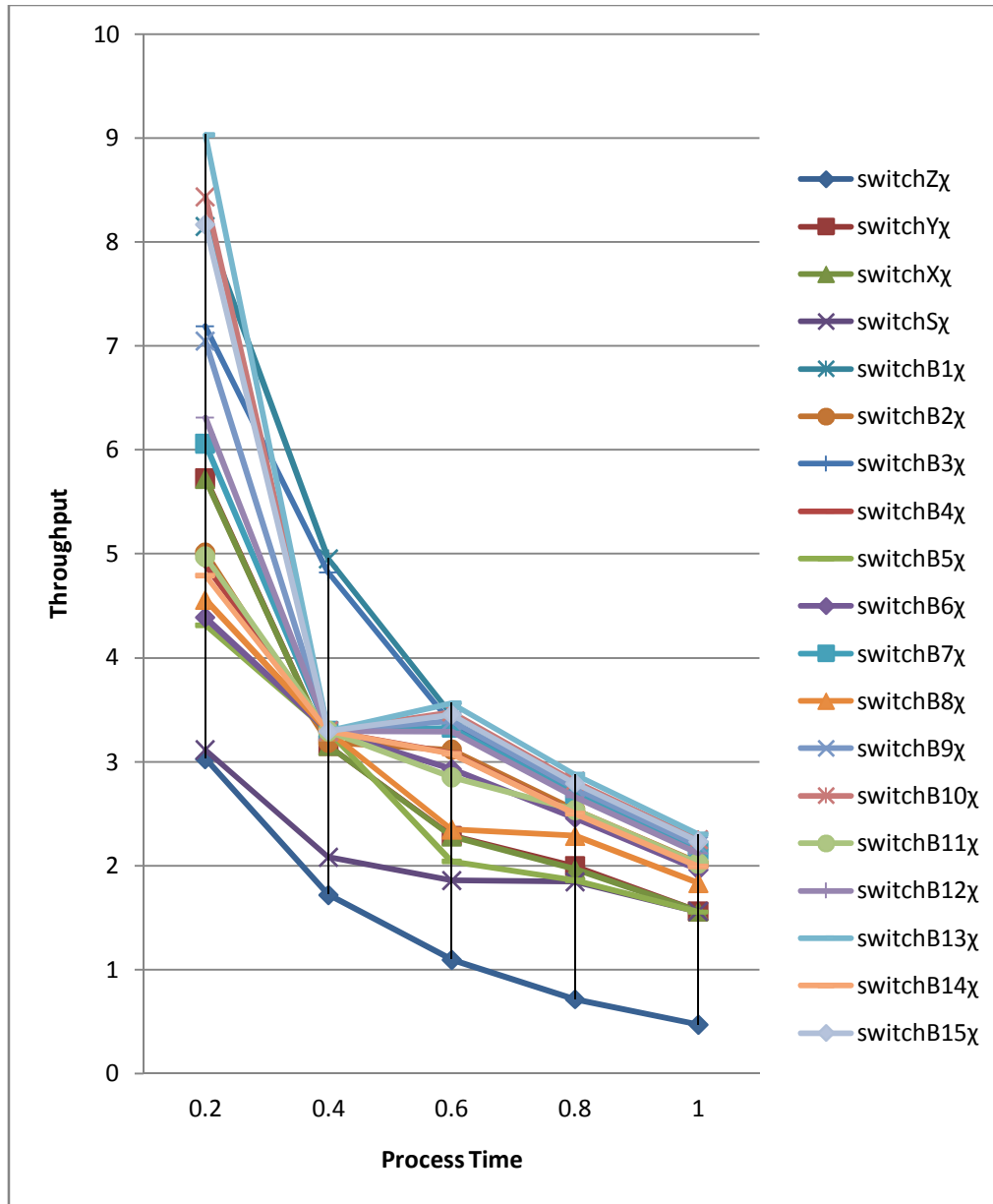


Figure 13: The graph of the Process Time against the Switches Throughput on the Network.

Figure 13 shows that the Internet switch, switch Z has lowest throughput during this experiment as Figure10. The core switch also recorded low throughput because all packets on the network accesses it to get to their destination. Switches B4-15 recorded same throughput

value during the second simulation. This shall be further investigated and discussed in the section 5.5 using the max number of users on the network. It is to note that the difference in the parameters used in Figure 10 and 13 is the number of user nodes.

5.4.3. EFFECT ON THE END TO END DELAY

Table 7 and Figure 14 below shows the effect of variations in process time on the end to end delay on the network when half of the total number of the users' node on the network is used. It could be noticed that the highest delay is experienced on the internet. The delays on the servers at the data centre are relative close.

Table 7: The Process Time and the Minimum End to End Delay on the Network

Process Time	Internet χ	Server1 χ	Server2 χ
0.2	1.2	0.8	0.8
0.4	2.4	1.6	1.6
0.6	3.6	2.4	2.4
0.8	4.8	3.2	3.2
1	6	4	4

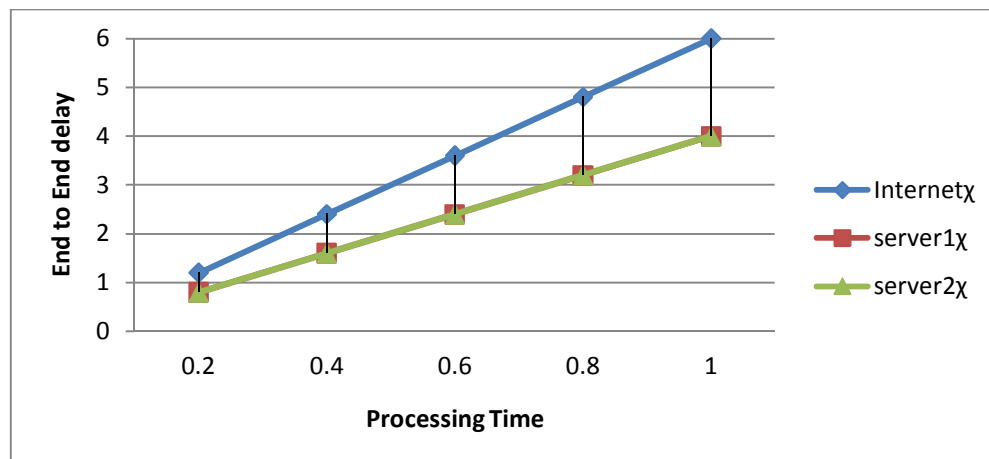


Figure 14: The Graph of the Processing Time and End to End Delay

Figure 14 shows that the inverse relationship between the end to end delay and the process time in Figure 11 is maintained, but server 2 does not record any constant value (see Figure 11) in its delay as a result of the equal number of user nodes used during this experiment.

5.5 VARIATION IN PROCESSING TIME USING MAX USER NODES

The maximum number of user nodes in Appendix C on each LAN at the access/edge switches was used for the simulation .The simulation runs were made for the internet, switches and servers at the data centre. This experiment was performed with the assumption that all the user nodes are busy.

5.5.1 EFFECT ON INTERNET AND THE SERVERS AT THE DATA CENTRE

Table 8 and Figure 15 depicts that increase in the processing time shows decline in the throughput on the internet and servers at the data centre.

Table 8: The Results of Process Time on the Internet and the Servers at the Data Centre.

Process Time	Internet χ	Server1 χ	Server2 χ
0.2	1.460	2.897	2.878
0.4	0.720	1.337	1.328
0.6	0.515	0.754	0.732
0.8	0.409	0.576	0.558
1	0.320	0.497	0.472

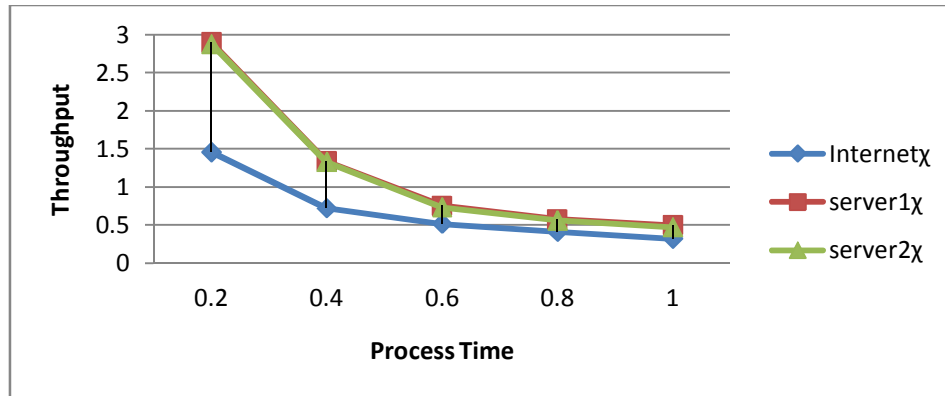


Figure 15: The graph of the Process Time against the Throughput on the Internet, and the Servers at the Data Centre.

It could be noted in Figure 15 that the Internet still has the lowest throughput as in Figure 12 when the number of users was increased. The flow of the graph for servers at the data centre is similar to that of Figure 12 as there is no significant impact recorded as the number of user increased.

5.5.2 EFFECT ON THE DISTIBUTION SWITCHES

Table 9: The Processing Time and Throughput on the Core Switch and Distribution Switches.

	Processing Time and Throughput				
Processing Time	0.2	0.4	0.6	0.8	1
switchZ χ	3.297	1.771	1.155	0.801	0.478
switchY χ	5.508	3.039	2.279	1.824	1.457
switchX χ	5.566	3.123	2.338	1.857	1.468
switchS χ	2.833	2.237	1.806	1.816	1.549
switchB1 χ	8.789	4.995	3.471	2.804	2.239
switchB2 χ	5.516	3.657	3.159	2.567	2.046
switchB3 χ	8.073	4.766	3.390	2.738	2.185
switchB4 χ	5.274	3.747	3.100	2.521	2.005
switchB5 χ	4.393	2.752	2.124	1.878	1.561
switchB6 χ	4.388	3.300	3.003	2.491	1.984
switchB7 χ	7.701	4.613	3.346	2.704	2.158
switchB8 χ	4.806	3.001	2.508	2.288	1.847
switchB9 χ	8.211	4.915	3.416	2.76	2.204
switchB10 χ	8.94	5.037	3.99	2.823	2.257
switchB11 χ	5.24	3.59	3.054	2.564	2.046
switchB12 χ	7.461	4.497	3.311	2.673	2.133
switchB13 χ	9.504	5.157	3.581	2.887	2.309
switchB14 χ	5.093	3.62	3.094	2.519	2.004
switchB15 χ	8.854	5.00	3.730	2.805	2.239

Table 9 and Figure 16 display the effect of the process time on the switches throughput. The throughput on the core switch is the lowest for the initial simulation followed by the internet switch. Switch Z displays low throughput throughout the experiment.

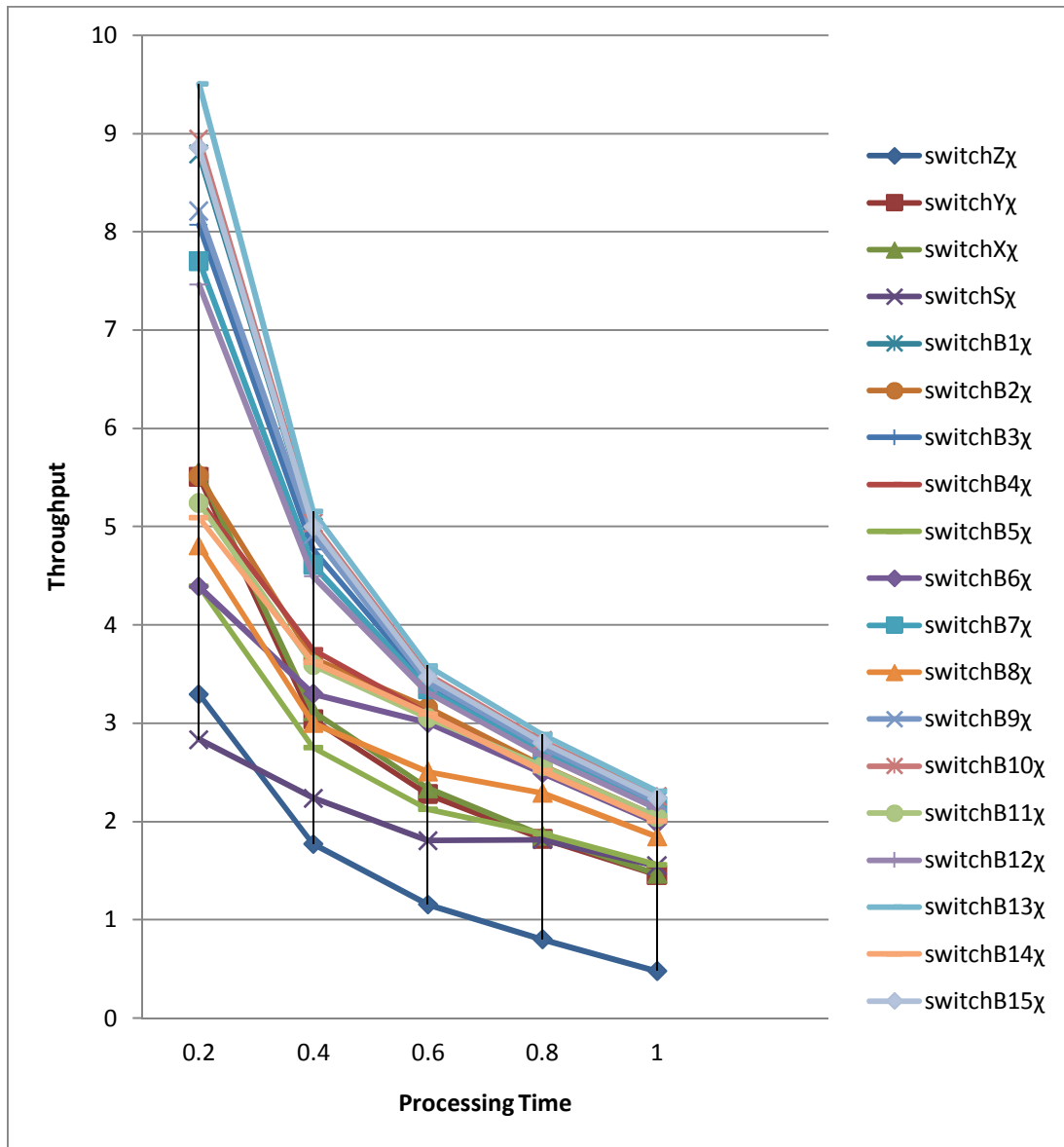


Figure 16: The Graph of the Process Time against the Throughput of the Distribution Switches.

Figure 16 shows that the core switch (switch S) is the lowest for the first simulation run and the internet switch (switch Z) remains the lowest all through the experiment. It could be noted that the graph flow in Figure 16 is a bit different from Figure 13. There was no constant throughput value on switch B4-B15 as shown in figure 13. This shows the impact of the increased number of users. The impact of arrival rate will be investigated on the switch Z to investigate the low throughput.

5.5.3 EFFECT ON END TO END DELAY

It could be noticed from Table 10 and Figure 17 that increases in the process time reflects an increase in the min end to end delay on the network. The internet displays the highest delay while the server at the data centre displays equal packet delay.

Table 10: The Process Time and End to End Delay on the Internet and the Servers at the Data Centre.

Process Time	Internet	Server1	Server2
0.2	1.2	0.8	0.8
0.4	2.4	1.6	1.6
0.6	3.6	2.4	2.4
0.8	4.8	3.2	3.2
1	6	4	4

The recorded values of the minimum end to end delay on the Internet and server 1 and 2 during this set of experimental simulations is detailed out in the Table 10 above. The delay is plotted against the processing time to view its flow in figure 17.

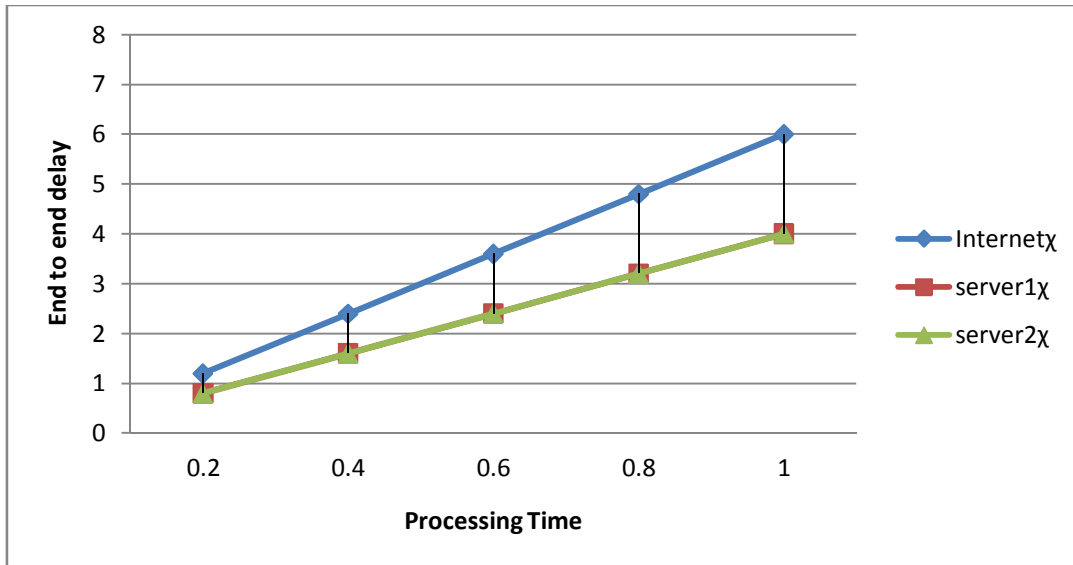


Figure 17: The Process Time and the End to End Delay on Internet and the Servers at the Data Centre.

In a similar fashion to Table 7 and Figure 14, Table 10 and Figure 17 shows that the minimum end to end delay on the network remains the same. This infers that the number of users' nodes on the network has little or no significant impact on the end to end delay but the increasing processing time has a significant impact on the network, because the end to end delay increases as the processing time increases.

5.6 VARIATION IN THE ARRIVAL RATE USING HALF USER NODE

The effect of packet arrival rate on the internet, switches and servers at the data centre throughput was investigated in this section. The effect on the end to end delay was also taken into account. Half the number of total user nodes in Appendix C on each LAN at the access/edge switches was used for the simulation. The simulation runs were made for the internet and the servers at the data centre.

5.6.1 EFFECT ON THE INTERNET AND DATA CENTRE SERVERS

Table 11: The Arrival Rate and the Corresponding Throughput on the Internet and Servers at the data Centre

Arrival Rate	Internet χ	Server1 χ	Server2 χ
2	1.60	2.18	2.17
4	1.61	2.18	2.18
6	1.62	2.18	2.18
8	1.68	2.28	2.28
10	1.67	2.27	2.27

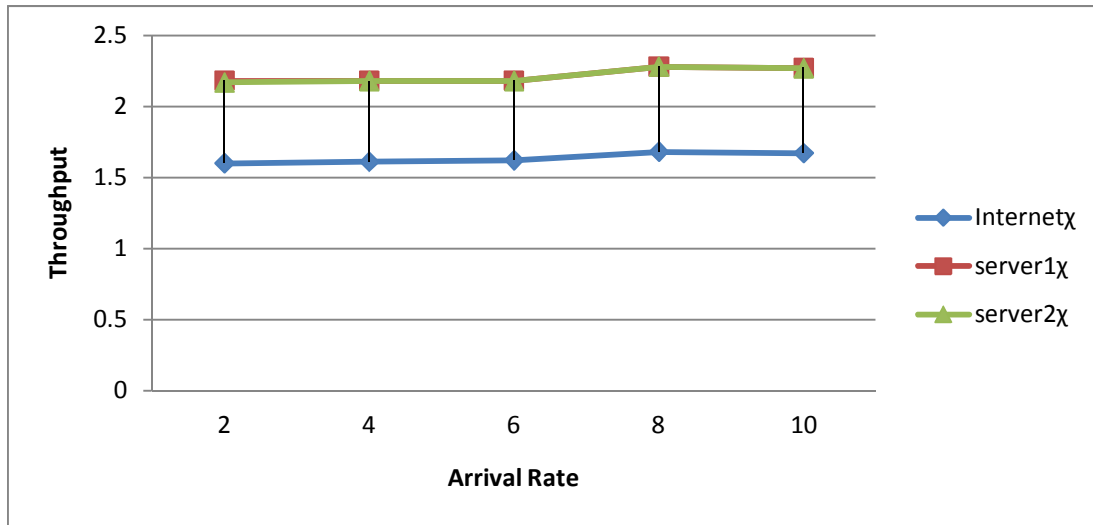


Figure 18: The Graph of the Arrival Rate against the Throughput on the Internet and the Servers at the Data Centre.

The recorded throughput value of the experiment is stated in Table 11 and the flow of the distribution is shown in Figure 18. It could be noted that when half of the user nodes is used the Internet still records low throughput compared to the servers 1 & 2 at the data centre. The data centre servers' records equal throughput. The impact of increased number of user nodes is discussed in section 5.7.

5.6.2 EFFECT OF ARRIVAL RATE ON THE DISTRIBUTION SWITCHES USING HALF NUMBER OF USER NODES

Table 12: The Arrival Rate and the Corresponding End to End Delay on the Switches

Arrival rate and the Throughput on the switches					
Arrival Rate	2	4	6	8	10
switch Z χ	1.816	1.811	2.056	2.326	2.276
switch Y χ	5.943	6.058	5.978	5.968	5.863
switch X χ	5.953	6.058	5.978	5.973	5.863
switch S χ	6.578	6.193	6.233	6.063	6.313
switch B1 χ	9.710	9.805	9.850	9.870	9.890
switch B2 χ	8.884	9.035	9.100	9.140	9.165
switch B3 χ	9.505	9.615	9.670	9.690	9.705
switch B4 χ	8.819	8.955	9.005	9.030	9.045
switch B5 χ	7.519	7.649	7.699	7.714	7.724
switch B6 χ	8.489	8.714	8.809	8.869	8.900
switch B7 χ	9.375	9.515	9.565	9.590	9.610
switch B8 χ	8.119	8.264	8.324	8.349	8.370
switch B9 χ	9.555	9.700	9.725	9.745	9.765
switch B10 χ	9.795	9.880	9.910	9.920	9.940
switch B11 χ	8.834	9.010	9.080	9.115	9.145
switch B12 χ	9.324	9.446	9.480	9.505	9.515
switch B13 χ	9.980	10.045	10.080	10.095	10.105
switch B14 χ	8.790	8.940	8.995	9.015	9.040
switch B15 χ	9.705	9.815	9.850	9.880	9.890

Figure 19 displays the results of the effect of the arrival rate on the switches on the network as stated in Table 12. It could be noticed that Switch Z still has low throughput all through the experiment.

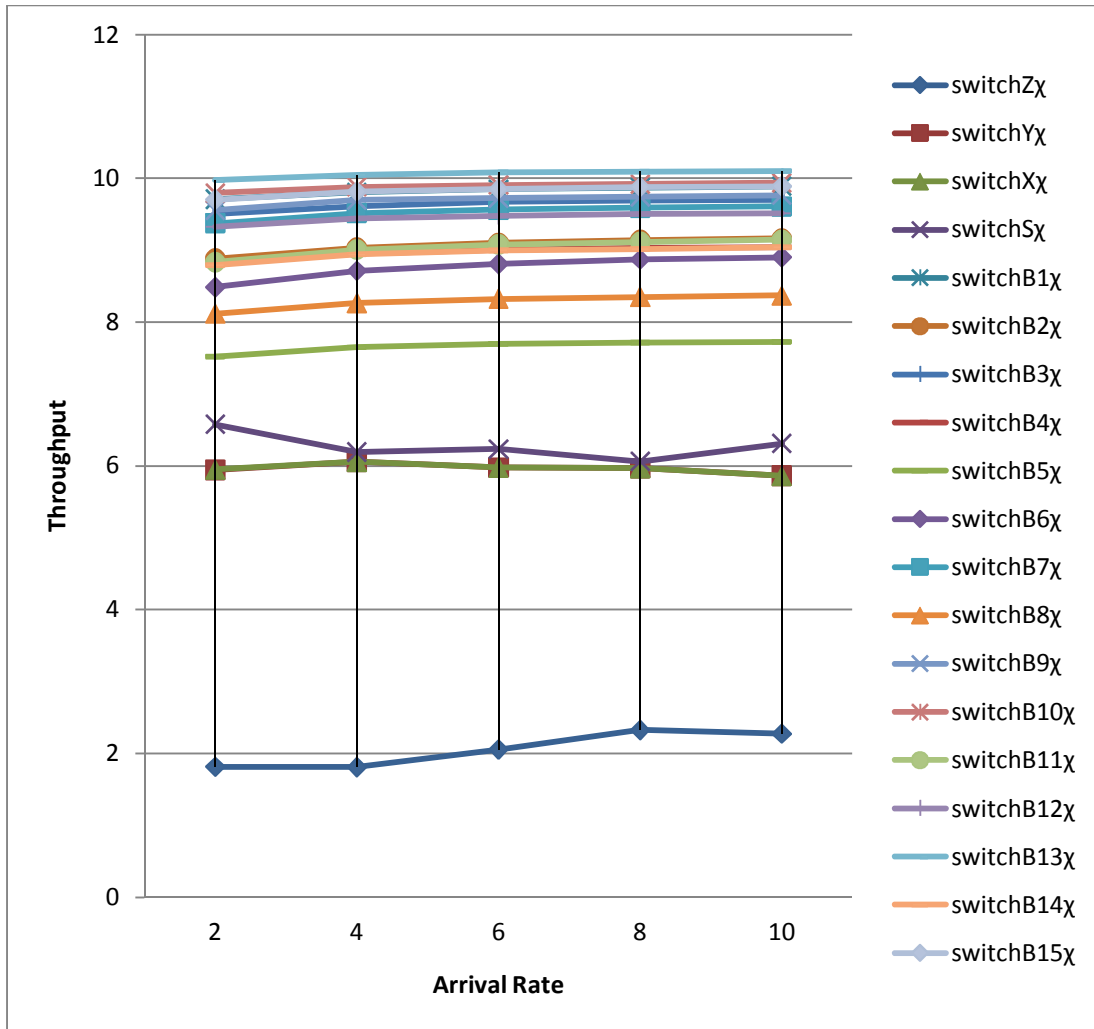


Figure19: The graph of arrival rate and throughput on the switches

Table 13: The Classification of Low, Medium and High Throughputs on the Distribution Switches

Low χ (0-4/s)	Medium χ (5-8/s)	High χ (8-10/s)
switch Z	Switch X & Y	Switch B1-B4
Nil	Switch S & B5	Switch B6-B15

Table 13 clearly classified the flow of the throughput in Figure 19 into high, medium and low throughput. The low and high throughput has a direct relationship with arrival rate. This is because the throughput increases as the arrival rate increases. The medium throughput shows

instability. This is could be further investigated with further simulation time. The throughput on switch Z is still low (refer to section 5.7.2 for results on further investigation).

5.6.3 EFFECT ON THE END TO END DELAY

The effect of the arrival rate on the end to end delay is displayed in Table 14 and Figure 20 below. It could be noticed that the min end to end delay on the network is constant. Except for the last run, this displays little or no significant impact.

Table 14: The Arrival Rate and the Corresponding End to End Delay on the Internet and Servers at the Data Centre.

Arrival Rate	Internet χ	Server1 χ	Server2 χ
2	1.2	0.8	0.8
4	1.2	0.8	0.8
6	1.2	0.8	0.8
8	1.2	0.8	0.8
10	1.2	1	0.9

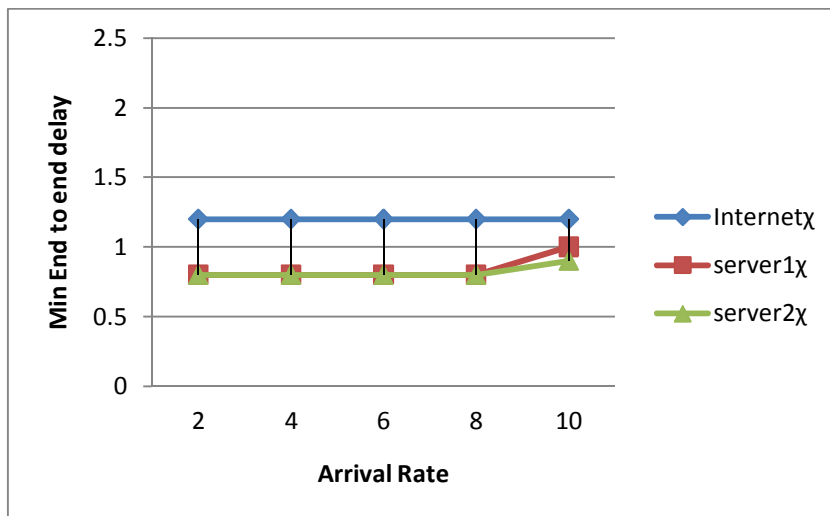


Figure 20: The Graph of Arrival Rate against the End to End delay

Table 14 and Figure 20 shows that increase in the arrival rate have no significant impact on minimum end to end on the network. It could be noticed that the Internet records flat value all through the experiment. Server 1 & 2 at the data centre has different value at the last run.

5.7 VARIATION IN THE ARRIVAL RATE USING MAXIMUM USER NODE ON THE NETWORK.

In this section a total number of 2211 user nodes (Appendix C) were used to perform the experiment and the corresponding effect on the throughput for the internet, switches and servers at the data centre were recorded. Result of the corresponding min end to end delay was also recorded in Figure 23 and Table 18.

5.7.1 EFFECT OF ARRIVAL RATE ON THE INTERNET AND SERVERS AT THE DATA CENTRE.

Table 15: The Results of Arrival Rate Variation the Internet and Servers at the Data Centre.

Arrival rate	Internet χ	Server1 χ	Server2 χ
2	1.600	2.530	2.465
4	1.615	2.540	2.535
6	1.585	2.220	2.230
8	1.620	2.345	2.340
10	1.625	2.840	2.850

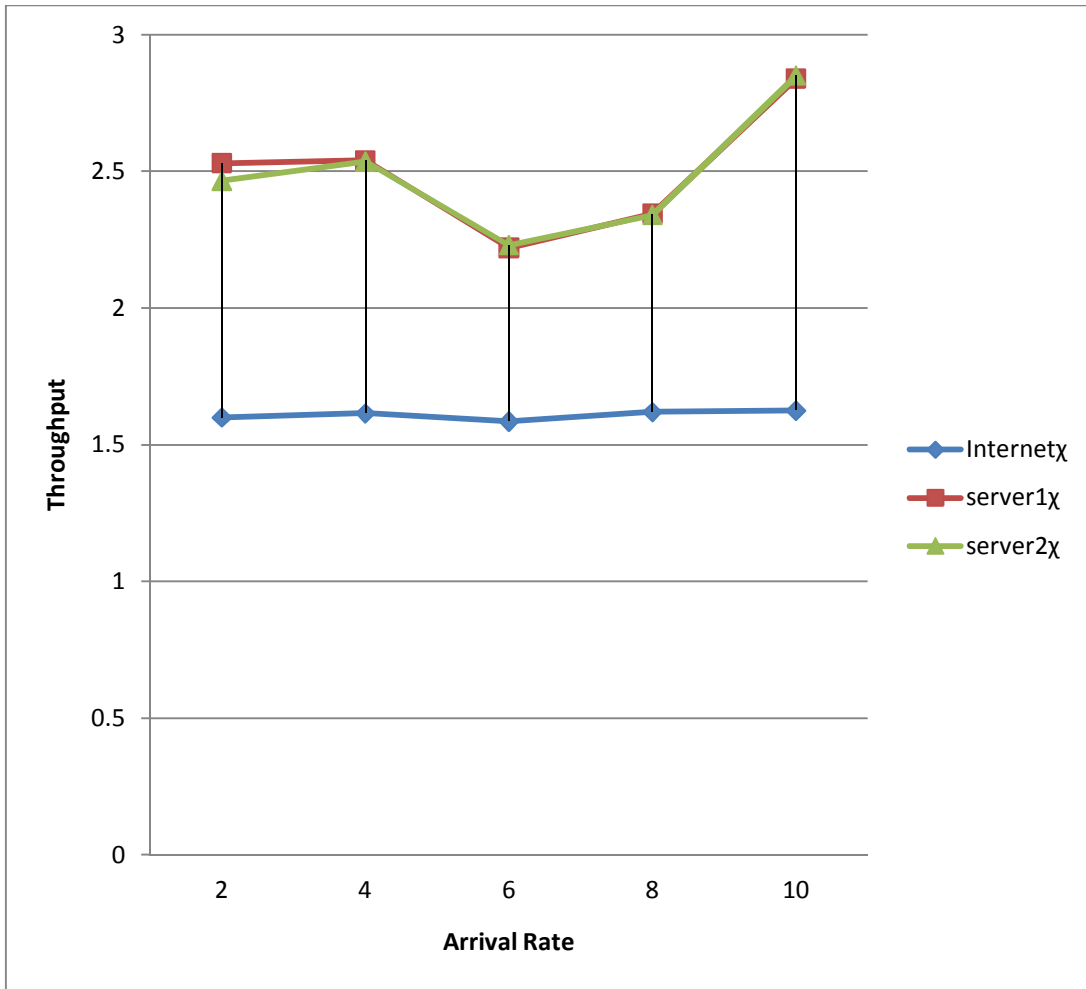


Figure 21: The Graph of Arrival Rate on Internet and the Servers at the Data Centre.

The increased arrival rate on the internet and servers shows significant impact on the throughput recorded on server 1 & 2 at the data center but little on the Internet. It could be noticed that as the arrival rate increases the throughput also increases, but a decline was experienced at rate of 6 packets/s and afterwards increases. This is as a result of the transient state.

5.7.2 EFFECT ON THE ARRIVAL RATE ON THE SWITCHES

Table 16: The Results of Arrival Rate Variation on the Distribution switches.

Arrival Rate	Arrival Rate and Throughput				
	2	4	6	8	10
switchZ χ	2.331	2.171	2.412	1.866	1.872
switchY χ	5.418	5.258	5.498	5.583	4.893
switchX χ	5.412	5.293	5.488	5.583	4.882
switchS χ	5.867	6.328	7.948	7.218	6.478
switchB1 χ	9.270	9.360	9.405	9.415	9.425
switchB2 χ	8.350	8.470	8.524	8.549	8.569
switchB3 χ	9.044	9.130	9.155	9.175	9.180
switchB4 χ	8.274	8.349	8.374	8.394	8.404
switchB5 χ	6.458	6.258	7.084	6.613	6.448
switchB6 χ	8.014	8.179	8.244	8.279	8.309
switchB7 χ	8.889	8.994	9.034	9.050	9.060
switchB8 χ	7.634	7.709	7.729	7.739	7.749
switchB9 χ	9.090	9.195	9.225	9.260	9.270
switchB10 χ	9.370	9.455	9.480	9.495	9.505
switchB11 χ	8.349	8.469	8.514	8.549	8.569
switchB12 χ	8.804	8.889	8.924	8.940	8.950
switchB13 χ	9.620	9.700	9.725	9.740	9.745
switchB14 χ	8.244	8.334	8.359	8.389	8.394
switchB15 χ	9.274	9.360	9.405	9.420	9.425

Figure 22 displays the results of the effect of the arrival rate on the switches on the network as stated in Table 16. It could be noticed that Switch Z still has low throughput all through the experiment.

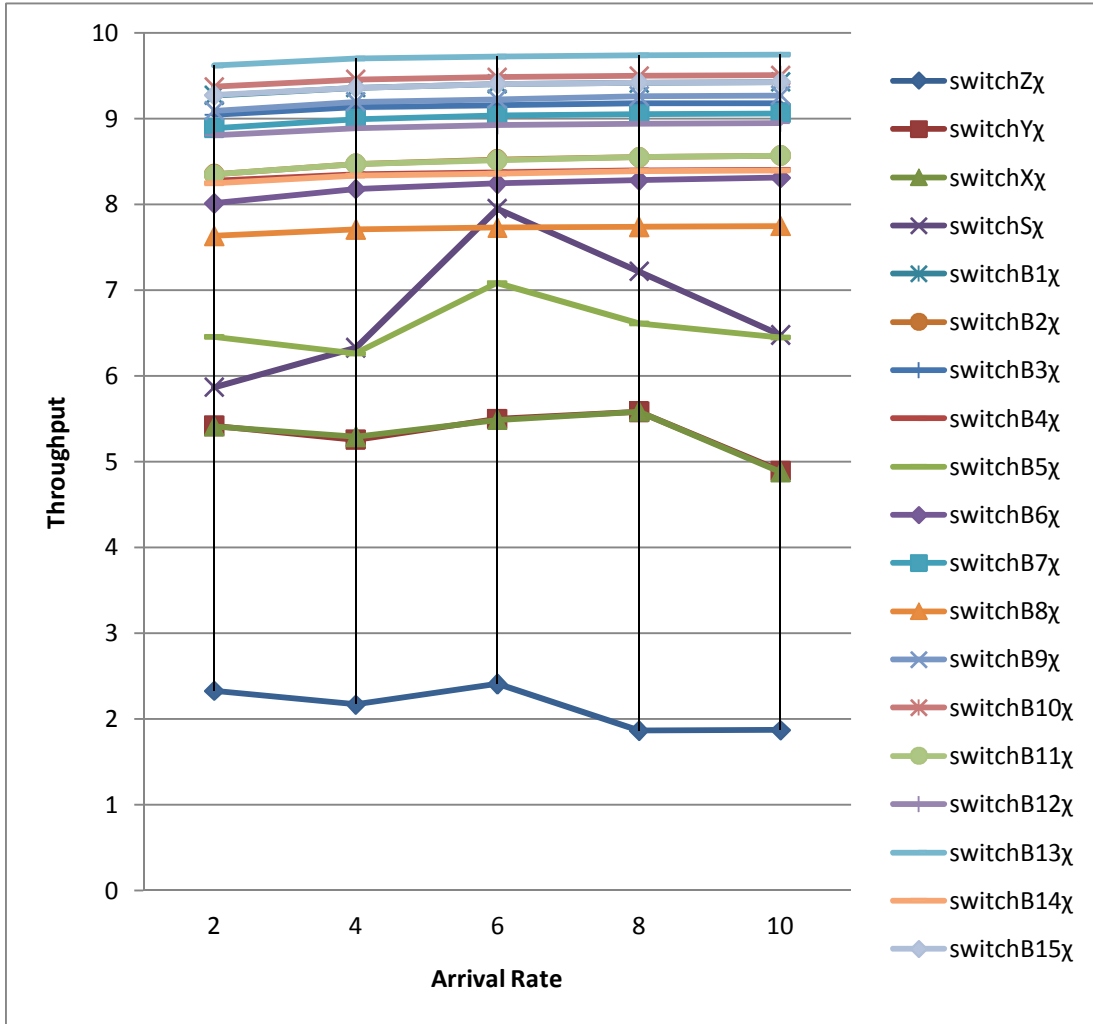


Figure 22: The Graph of Arrival Rate on the Distribution Switch.

Figure 22 above can be further classified into low, medium and high throughput as there are distinct differences in the values. Table 17 shows that the switch Z still displays low throughput. Core switch (S), switch X and Y at the data centre, switch B5 and B8 displays a medium throughput while the rest of the switches has high and increasing throughput all through the experiment.

Table 17: The Classification of Low, Medium and High Throughputs on the Distribution Switches

Low χ (0-4/s)	Medium χ (5-8/s)	High χ (8-10/s)
switch Z	Switch X & Y	Switch B1-B4
Nil	Switch S ,B5& B8	Switch B6-B15

5.7.3 EFFECT ON END TO END DELAY

Figure23 and Table 18 below shows that increase in the process time reflects no significant impact on the min delay on the network. But it could be noticed that the internet displays the highest delay values on the network. The server at the data center displays equal packet delay.

Table 18: The Results of Arrival Rate Variation on the Minimum End to End Delay.

Arrival Rate	Internet χ	Server1 χ	Server2 χ
2	1.200	0.800	0.801
4	1.201	0.800	0.800
6	1.200	0.800	0.800
8	1.200	0.800	0.800
10	1.200	0.800	0.800

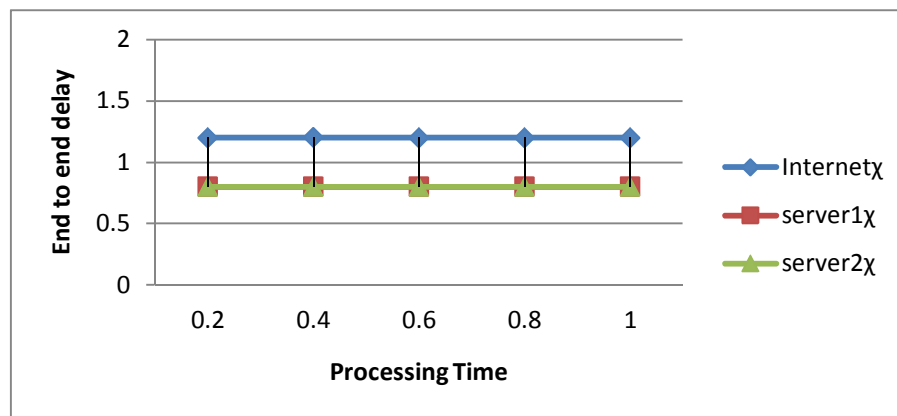


Figure 23: The Graph of Arrival Rate on the End to End Delay on the Network.

5.8 UTILIZATION OF THE INTERNET, SERVERS AND SWITCHES

Utilization (U) = χS is the percentage of time that the switches are busy. Table 19 and 20 shows the utilization while $0 \leq U \leq 1$, the idle time and the fraction of packets dropped per second when process time is 0.2s for total user nodes. Switches with $U=1$ has no idle time while processing. Switch Z in has 66% to process and rest for 34% per second. The dropped packet fraction infers the packets dropped per second. The distribution switches of concern are located at the computer centre, FSKP, FPP/FSK, Rack A Perpustakaan, Kolej Eon, BKP, FWB, Bukit Katchi, Muamalat, FTM, Faculty of Economics, PPK, and the switches at the data centre. The switches are of concern because they do not have a resting time while processing. Appendix F and G shows that fraction of dropped packets increases as S increases when the number of user node is half and maximum. The utilization was derived using the information recorded for variations of process time using maximum number of user nodes on the network.

Table 19: The Utilization of the Internet and Servers at the Data Centre when using the Maximum User Nodes

	S=0.2	Utilization	Dropped packet fraction	Idle Time
Internet	1.460	0.292	0	0.270
server 1	2.897	0.5794	0	0.4206
server 2	2.878	0.5756	0	0.4244

Table 19 above shows that the internet is underutilised and the servers at the data centre is also not well utilised. This implies that the Internet and servers at the data centre can still process higher number of packets as compared to what they are currently processing. Refer to appendix H.

Table 20: The Utilization of the Distribution Switches when using the Maximum User Nodes

Switch	S=0.2	Utilization	Dropped packet fraction	Idle Time
switchZ	3.297	0.6594	0	0.3406
switchY	5.508	1	0.1016	0
switchX	5.566	1	0.1132	0
switchS	2.833	0.5666	0	0.4334
switchB1	8.789	1	0.7578	0
switchB2	5.516	1	0.1032	0
switchB3	8.073	1	0.6146	0
switchB4	5.274	1	0.0548	0
switchB5	4.393	0.8786	0	0.1214
switchB6	4.388	0.8776	0	0.1224
switchB7	7.701	1	0.5402	0
switchB8	4.806	0.9612	0	0.0388
switchB9	8.211	1	0.6422	0
switchB10	8.94	1	0.788	0
switchB11	5.24	1	0.048	0
switchB12	7.461	1	0.4922	0
switchB13	9.504	1	0.9008	0
switchB14	5.093	1	0.0186	0
switchB15	8.854	1	0.7708	0

5.9 SUMMARY

In conclusion, the simulation model has successfully displayed the throughput and end to end delay to the internet and data-servers on the network. The various throughputs on the core switch and distribution switches were also reflected. The variation in processing time, arrival rate and number of user nodes shows much impact on the switches throughput than the internet and servers at the data centre. During the experiments, increase in the processing time and the arrival time increases the end to end delay on the network. With obviously low throughput on the internet for the first simulation run and subsequent variations. It was discovered that the average throughput on switch Z that leads to the internet remains constantly low.

The utilization of the Internet and servers at the data centre is low. This implies that the servers and Internet can be not of concern and can still perform satisfactorily when the number of user is increased. Further investigation on the utilization of the switches shows that distribution switch located at the computer centre, FSKP, FPP/FSK, Rack A Perpustakaan, Kolej Eon, BKP, FWB, Bukit Katchi, Muamalat, FTM, Faculty of Economics, PPK, and the switches at the data centre are bottleneck prone as the utilization is 1 and packets are dropped per second. This is as a result of switch processing time, packet arrival rate, number of users and the switch processing power. This can stand as a starting point in future utilization of computerised models to simulate packets transmission on the network.

CHAPTER SIX

CONCLUSION

This study concludes with a short summary of research contribution, problems and limitations and proposal for future works. A simulation model has been developed for the UUM wired LAN. We also endeavoured to use the model to simulate the real system in the university.

6.1 RESEARCH CONTRIBUTION

This research study has the opportunity to introduce simulation modelling to the management of the computer centre that manages the LAN in University of Utara Malaysia. Prior to this study, there was no simulation model to use in measuring the performance of the network. Performance metrics such as throughput, end to end delay and utilization of hardware on the network were presented for the use of the management of UUM computer centre.

The simulation modelling technique should be well embraced to foster the development of simulation models that will make detection of bottle-neck area easier on the communication network. Simulation models of communication networks also assist in building the capacity of the network.

6.2 PROBLEMS AND LIMITATION

The major challenge encountered during the course of this study was on data collection. In order to derive an accurate model, specific data is required. The data has to be as accurate as it could be. Some of the needed data were not available at the computer centre. Therefore, a

reasonable assumption was made with a time study and we presented the performance metrics values.

6.3 RECOMMENDATION AND FUTURE WORKS

This research work has made use of the computerised simulation as a tool to analyse and detect the bottle neck nodes on the on a computer network. The study made use of simulation concept and the applicable methodology in the course of the study. Simulation has variety of applications and it assist in saving time to practically expend alternate ways and what to do to a problem prone section of a network. A large and complicated project may be capital intensive but the resulting return on investment brought about by improved and better performance of the network to the clients can not be overlooked.

It is recommended that the management of Computer Centre make use of the simulation model approach to analyse the performance of the network. The capacity and loads on the switches discussed in section 5.9 should be reviewed. The centre's aim is to deliver quality service to the stakeholders and other users in the academic community could be sustained if the processing time on the switches is kept at the barest minimum. The invested capital sum in upgrading the initial technology previously been used can be made to have a good return on investment by a good performance of the network. Also the simulation model approach can be used by the management for capacity building and future network expansion.

The network is presently operating under an environment that some of the nodes are heavily loaded. Further study could be investigation of the utilization of the access/edge switches on the network as Appendix E. shows that the network could still accommodate expansion. A

performance simulation study of a computer network would assist in identifying the bottleneck area and sections of the network for rectification.

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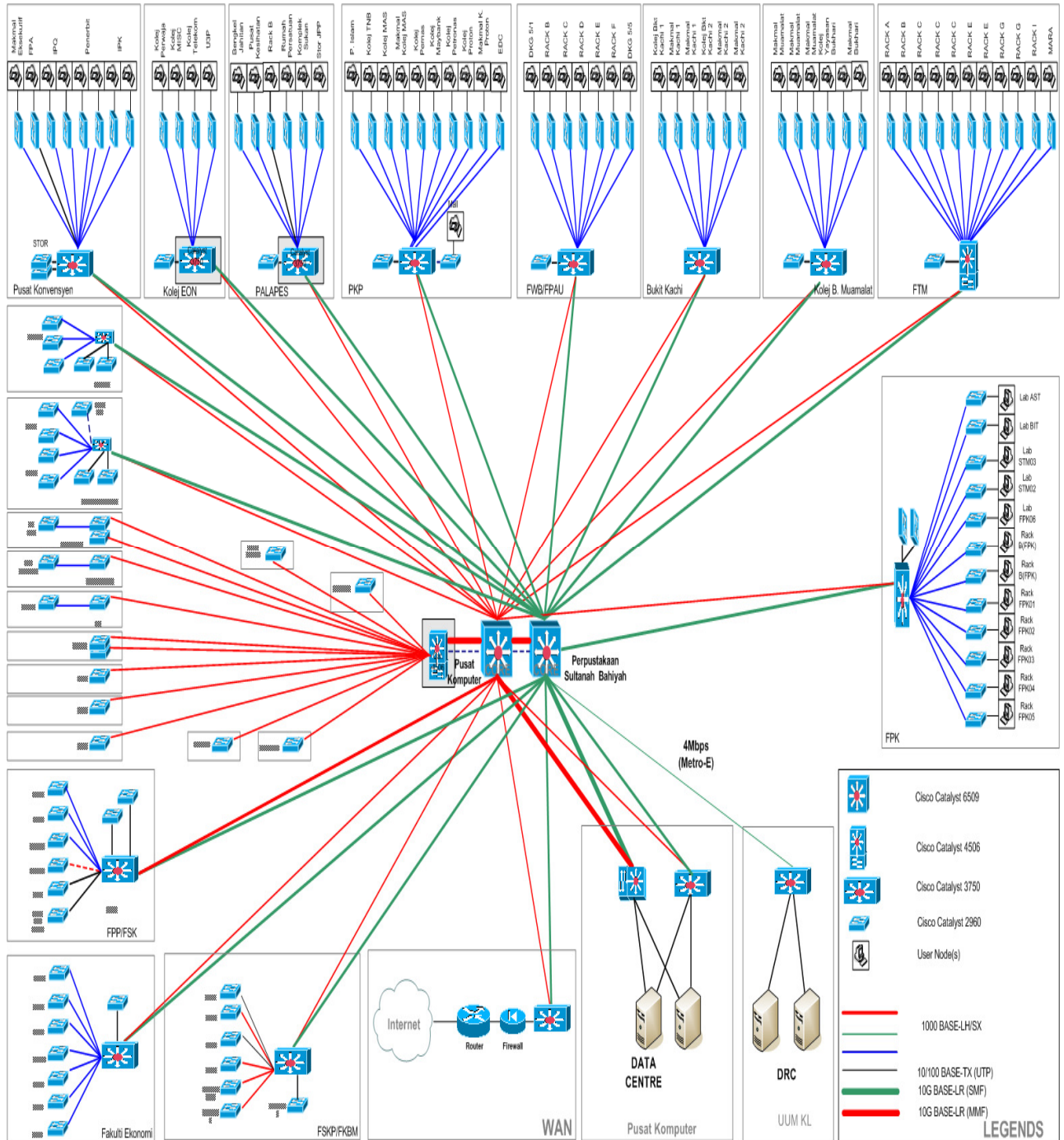
APPENDIX A: RESEARCH SCHEDULE (GANTT CHART)

TASKS	DAYS	WEEK											
		1	2	3	4	5	6	7	8	9	10	11	12
Collection of Data (Network Parameters)	3												
Model Design	3												
Coding Process	30												
Validate the Model	7												
Running of Experiments	5												
Analyze results	5												
Documentation	5												
Total	58	3	6	5	5	5	5	3	6	5	6	5	4

The above chart is time schedule from the beginning of the study to the end of the study. The schedule is prepared in 12weeks.

APPENDIX B: UUM LOCAL AREA NETWORK (WIRED) DIAGRAM

UUM Network Schematic Diagram



APPENDIX C: TOTAL NUMBER OF USER NODES ON THE NETWORK

Lab Management

COMPUTER CENTER

No	Location	Lab	No of Labs	No of PCs	Lab Assisstant
1	Business Management Building	FP 01	1	20	Harison/Intan
		FP 02	1	41	Intan Rosmida
		FP 03	1	41	Harison Hassan
2	Accounting Building	FPK 01	1	41	Norannajah
		Wireless Lab	1		
		FPK 03	1	41	Norbaitirah
		FPK 04	1	41	Zuhaida
		Wireless Lab	1		
		FPK 06	1	41	Norazua
		FPK 07	1	41	Norazua
3	Economic Building	FE 01	1	41	Hamid
		FE 02	1	41	Hamid
4	Postgraduate Building	SS 01	1	21	Farizal
5	Sosial and Human Development Building	FPSM 01	1	20	Hazura
		FPSM 02	1	20	Hazura
6	Computer Center	Wireless Lab	1		
	TOTAL		16	450	

RESPONSIBILTY CENTER

No	Location	Lab	No of Labs	No of PCs	Lab Assisstant
1	Quantitative Science Building	FSK 01	1	50	Kolej
		FSK 02	1	41	Kolej
2	Information Technology Building	MM1	1	40	Kolej
		MM2	1	39	Kolej

		MM3	1	39	Kolej
		MASTER IT	1	30	Kolej
		BIT 1	1	43	Kolej
		BIT 2	1	32	Kolej
		SEDB	1	39	Kolej
		RANGKAIAN	1	40	Kolej
3	Cognitive Science and Education Building	FSKP 01	1	41	Kolej
		FSKP 02	1	25	Kolej
4	Management of Technology Building	MOT 01	1	30	Kolej
		MOT 02	1	36	Kolej
		MOT 03	1	42	Kolej
5	Registrar Department	EKSEKUTIF	1	25	Farizal
6	Sultanah Bahiyah Library	P'PUSTAKAAN	3	92	PTJ
7	UUM Mosque	Masjid	1	31	PTJ
	TOTAL		20	715	

SERINDIT.COM

No	Location	Lab	No of Labs	No of PCs	Lab Assisstant
1	Fakulti Pemb. Sosial dan Manusia	FPSM 03	1	33	Serindit
2	Fakulti Pengajian A/bangsa	Makmal FPA	1	30	Serindit
3	Fakulti Pengurusan Awam dan Undang-Undang	MAKMAL 01	1	51	serindit
		MAKMAL 02	1	37	serindit
4	Fakulti Kom dan Bahasa Moden	Makmal 01	1	45	serindit
5	Fakulti Kewangan dan Perbankan	MAKMAL 03	1	52	serindit
		MAKMAL 04	1	52	serindit
		MAKMAL 05	1	47	serindit
STUDENT RESIDENTIAL HALL					
6	DPP EON	A	1	41	Serindit
7	DPP Petronas	A	1	19	Serindit
8	DPP Tradewinds	A	1	39	Serindit
9	DPP MAS	A	1	19	Serindit
		B	1	20	Serindit
10	DPP TNB	A	1	40	Serindit
11	DPP PROTON	A	1	21	Serindit
		B	1	14	Serindit

12	DPP SIME DARBY	A	1	41	Serindit
13	DPP PERWAJA	A	1	31	Serindit
14	DPP TELEKOM	A	1	18	Serindit
		B	1	21	Serindit
15	DPP MISC	A	1	36	Serindit
16	DPP Yayasan Bukhary	A	1	82	Serindit
17	DPP Muamalat	A	1	32	Serindit
		B	1	20	Serindit
		C	1	20	Serindit
18	DPP Bank Rakyat	A	1	41	Serindit
		B	1	41	Serindit
19	DPP Bukit Kachi 2	A	1	41	Serindit
		B	1	41	Serindit
20	DPP Maybank	A	1	21	Serindit
	TOTAL		30	1046	
	OVERALL TOTAL		66	2211	

NO OF LAB:

66

NO OF PC:

2211

APPENDIX D: ROUND TRIP TIME ON THE NETWORK

N/S	Distribution	RTT(ms)
1	Internet	5.00
2.	Data Centre1	1.00
3.	Data Centre2	1.00
4.	Canselori	5.67
5.	Eon	4.58
6.	FE	6.14
7.	FKBM	5.77
8.	FPK	3.84
9.	FPP	5.40
10.	FTM	3.16
11.	FWB	5.50
12.	KACHI 1	5.60
13.	KOVENSYEN	5.73
14.	MUALAMAT	5.20
15.	PALAPES	5.47
16.	PKP	6.04
17.	PSB	5.27

APPENDIX E: THE SWITCH PORT USAGE ON THE NETWORK.

Hardware	Number on the network	Number of Ports	Total port Number	Ports Engaged	Ports Not Engaged
Access switches	113	24	2712	2211	501
Distribution switches	18	48	864	226	638
Core switch	2	48	96	36	60

**APPENDIX F: DISTRIBUTION SWITCH UTILIZATION (HALF
NUMBER OF USER-NODES)**

Switch	S=0.2	U	Dropped packet fraction	Idle Time	S=0.4	U	Dropped packet fraction	Idle Time	S=0.6	U	Dropped packet fraction	Idle Time	S=0.8	U	Dropped packet fraction	Idle Time	S=1	U	Dropped packet fraction	Idle Time
switchZ		0.6594	0	0.3406		0.688	0	0.312		0.6576	0	0.3424		0.5728	0	0.4272		0.472	0	0.528
switchY		1	0.1456	0		1	0.2624	0		1	0.373	0		1	0.5968	0		1	0.562	0
switchX		1	0.1436	0		1	0.2624			1	0.371	0		1	0.5728	0		1	0.562	0
switchS		0.6226	0	0.334		0.8332	0	0.1668		1	0.114	0		1	0.4776	0		1	0.559	0
switchB1		1	0.6298	0		1	0.9812	0		1	0.070	0		1	1.232	0		1	1.230	0
switchB2		1	0.0026	0		1	0.2732	0		1	0.869	0		1	1.033	0		1	1.028	0
switchB3		1	0.438	0		1	0.928	0		1	0.020	0		1	1.176	0		1	1.174	0
switchB4		0.977	0	0.023		1	0.318	0		1	0.849	0		1	1.006	0		1	0.996	0
switchB5		0.8626	0	0.1374		1	0.318	0		1	0.224	0		1	0.487	0		1	0.554	0
switchB6		0.8774	0	0.1226		1	0.318	0		1	0.758	0		1	0.965	0		1	0.960	0
switchB7		1	0.2118	0		1	0.318	0		1	0.995	0		2	1.152	0		1	1.148	0
switchB8		0.912	0	0.088		1	0.318	0		1	0.411	0		1	0.830	0		1	0.834	0
switchB9		1	0.4092	0		1	0.318	0		1	1.035	0		1	1.196	0		1	1.194	0
switchB10		1	0.6868	0		1	0.318	0		1	1.087	0		1	1.250	0		1	1.250	0
switchB11		0.9944	0	0.0056		1	0.318	0		1	0.71	0		1	1.028	0		1	1.023	0
switchB12		1	0.2616	0		1	0.318	0		1	0.973	0		1	1.127	0		1	1.123	0
switchB13		1	0.8062	0		1	0.318	0		1	1.138	0		1	1.301	0		1	1.303	0
switchB14		0.9578		0.0422		1	0.318	0		1	0.846	0		1	1.003	0		1	0.995	0
switchB15		1	0.6338	0		1	0.318	0		1	1.072	0		1	1.233	0		1	1.233	0

APPENDIX G: THE DISTRIBUTION SWITCH UTILIZATION (MAX USER NODES)

Switch	S=0.2	U	Dropped packet fraction	Idle Time	S=0.4	U	Dropped packet fraction	Idle Time	S=0.6	U	Dropped packet fraction	Idle Time	S=0.8	U	Dropped packet fraction	Idle Time	S=1	U	Dropped packet fraction	Idle Time
switchZ		0.6594	0	0.3406		0.7084	0	0.2916		0.693	0	0.307		0.6408	0	0.3592		0.478	0	0.522
switchY		1	0.1016	0		1	0.2156	0		1	0.3674	0		1	0.4592	0		1	0.457	0
switchX		1	0.1132	0		1	0.2492	0		1	0.4028	0		1	0.4856	0		1	0.468	0
switchS		0.5666	0	0.4334		0.8948	0	0.1052		1	0.0836	0		1	0.4528	0		1	0.549	0
switchB1		1	0.7578	0		1	0.998	0		1	10.826	0		1	12.432	0		1	1.239	0
switchB2		1	0.1032	0		1	0.4628	0		1	0.8954	0		1	10.536	0		1	1.046	0
switchB3		1	0.6146	0		1	0.9064	0		1	1.034	0		1	11.904	0		1	1.185	0
switchB4		1	0.0548	0		1	0.499	0		1	0.86	0		1	10.168	0		1	1.005	0
switchB5		0.8786	0	0.1214		1	0.101	0		1	0.2744	0		1	0.5024	0		1	0.561	0
switchB6		0.8776	0	0.1224		1	0.32	0		1	0.8018	0		1	0.9928	0		1	0.984	0
switchB7		1	0.5402	0		1	0.845	0		1	10.076	0		1	11.632	0		1	1.158	0
switchB8		0.9612	0	0.0388		1	0.200	0		1	0.5048	0		1	0.8304	0		1	0.847	0
switchB9		1	0.6422	0		1	0.966	0		1	10.496	0		1	1.208	0		1	1.204	0
switchB10		1	0.7880	0		1	1.015	0		1	10.994	0		1	12.584	0		1	1.257	0
switchB11		1	0.0480	0		1	0.436	0		1	0.8324	0		1	10.512	0		1	1.046	0
switchB12		1	0.4922	0		1	0.798	0		1	0.9866	0		1	11.384	0		1	1.133	0
switchB13		1	0.9008	0		1	1.062	0		1	11.486	0		1	13.096	0		1	1.309	0
switchB14		1	0.0186	0		1	0.448	0		1	0.8564	0		1	10.152	0		1	1.004	0
switchB15		1	0.7708	0		1	1	0		1	10.838	0		1	1.244	0		1	1.239	0

**APPENDIX H: THE INTERNET AND SERVERS AT THE DATA
CENTRE UTILIZATION (MAX USER NODES)**

	S=0.2	Utilization	Dropped packet fraction	Idle Time
Internet	1.460	0.292	0	0.27
server 1	2.897	0.5794	0	0.4206
server 2	2.878	0.5756	0	0.4244
Switch	S=0.4	Utilization	Dropped packet fraction	Idle Time
Internet	0.720	0.288	0	0,712
server1	1.337	0.5348	0	0.4652
server2	1.328	0.5312	0	0.4688
Switch	S=0.6	Utilization	Dropped packet fraction	Idle Time
Internet	0.515	0.309	0	0.691
server1	0.754	0.4524	0	0.5476
server2	0.732	0.4392	0	0.5608
Switch	S=0.8	Utilization	Dropped packet fraction	Idle Time
Internet	0.409	0.3272	0	0.6728
server1	0.576	0.4608	0	0.5392
server2	0.558	0.4464	0	0.5536
Switch	S=1.0	Utilization	Dropped packet fraction	Idle Time
Internet	0.320	0.320	0	0.68
server1	0.497	0.497	0	0.503
Server2	0.472	0.472	0	0.528