ANALYSIS OF INTERNET TRAFFIC IN ASSUMPTION UNIVERSITY

by

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Faculty of Engineering
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ANALYSIS OF INTERNET TRAFFIC IN ASSUMPTION UNIVERSITY

A thesis

submitted to the Faculty of Engineering

by

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in partial fulfillment of the requirements

for the degree of

Master of Engineering in Broadband Telecommunications

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Bangkok, Thailand

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ABSTRACT

The paper offers the methodology of using Queuing theory to model and analyze the Internet network. An opinion is given on what type of Queuing system is most suitable for analyzing the Internet network in Assumption University. This opinion is based on results from measurements, calculations and simulations. It also offers a frame work that can be used to increase the performance of the network.

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CHAPTER1. INTRODUCTION

The Internet is very popular and widely use nowadays. Internet access and the ability of corporate internetworking to deliver essential services in the face of increasing traffic and changing traffic patterns are therefore very important. The need for a network demand model is essential. The ability to anticipate bandwidth needs is critical for efficiently managing the provisioning of the service and for important business decisions. To achieve this goal, the development of a network demand model and simulation tool is essential. This study attempts to use queuing theory to increase the performance of the Internet.

One of the most important performance measures of a data network is the average delay required to deliver a packet from origin to destination. Furthermore, delay considerations strongly influence the choice and performance of network algorithms, such as routing and flow control. For these reasons, it is important to understand the nature and mechanism of delay, and the manner in which it depends on the characteristics of the network.

The main topic of this paper is about analyzing the Internet traffic. This is done analytically by using Queuing theory which is the primary methodological framework for analyzing network delay. The importance of this topic is that recently the number of Internet users in Thailand has been increasing rapidly. This can be seen in table1.1

Table 1.1 Rough Estimate of Number of Internet Users in Thailand [1]

Number of Internet users in Thailand	June 97 (Persons)	December 97 (Persons)	December 98 (Persons)
1.GovernmentUniversity	50,000	100,000	120,000
2.Private Universities	80,000	150,000	200,000
3.Commercial andTechnicalColleges	20,000	100,000	200,000
4.Highschools and Grade Schools.	20,000	100,000	200,000
5.Government,State Enterprise, Private	40,000	100,000	200,000
Total	210,000	550,000	920,000

From the table you will see that the number of users in Thailand has increase about 67% from 1997 to 1998 and have a trend to increase every year. So if the Internet traffic can not be analyzed effectively then one of the data network problem that is slow bit rate available to the end user can occur. Followings are the steps used to analyze the Internet traffic in this paper.

1. Measurement of the Internet traffic by using the network analyzer.
2. Apply the measurement results statistics to Queuing theory.
3. Computer simulation using Queuing statistics from the measurement results.
4. Computer simulation of the network (using the Opnet simulation program).
5. Comparison of the results from 2, 3, and 4.

The analysis is done on the Internet traffic in Assumption University (ABAC). The Assumption University data network is called AuNet. The AuNet campus network spans the whole Au campus providing network connectivity and computing for Au community. Optical fiber is deployed in the high speed backbone and building riser. The backbone runs at 100 Mbps using FDDI technology while 10 Mbps Ethernet are deployed in the distributed network and local area network(LAN).

This paper consists of 8 chapter:

The first chapter is an Introduction to the topic of this paper which contains the outline of the research.

The second chapter provided the background knowledge necessary for the research which are: a brief history of the Internet, what is TCP/IP, components of the Internet, a brief history of Internet in Thailand, works previously done and Queuing theory .

The third chapter is about the measurement results of Internet traffic in ABAC by using the Sniffer Network Analyzer. The results are presented using various graphs. The Probability Density Function (pdf) used to characterize the traffic are found.

In the fourth chapter the traffic characteristics found in chapter 3 are then applied to the following queuing systems.

- M/D/1 Queuing system
- D/D/1 Queuing system
- G/D/1 Queuing system

and present the results of calculation when changing the service rate from 10 Mb/s and 100 Mb/s.

In the fifth chapter the traffic characteristics from chapter 3 are used in the Opnet simulation program. It presents graphs of the expected number of packet in system (N) and the total waiting time in the system (T).

In the sixth chapter, the entire AuNet is simulated using the Opnet module. A model of an improved network is also simulated. Also present are problems encountered during the modeling of the network.

In chapter 7 two topic are discussed. The first is the comparison of the results from calculation (chapter 4), simulation (chapter 5),and modeling of AuNet. The second is how performance of network, base on the results in this paper can be improved.

In the last chapter is concluded about this paper.

This thesis's contribution

This paper offers the methodology of using the Queuing theory to analyze the network. The opinion is given on what type of Queuing system is suitable for analyzing the Internet network in ABAC and why. It also offer a frame work used to find the problem to increase the performance of a network.

CHAPTER 2. BACKGROUND KNOWLEDGE

This chapter present the background knowledge necessary for this work those background are: a brief history of the Internet, what is TCP/IP, components of the Internet, a brief history of Internet in Thailand, works previously done and Queuing theory .

2.1 A Brief History of the Internet [1]

In 1973, the U.S. Defense Advanced Research Projects Agency (DARPA) initiated a research program to investigate techniques and technologies for interlinking packet networks of various kinds. The objective was to develop communication protocols which would allow networked computers to communicate transparently across multiple, linked packet networks. This was called the Internet project and the system of networks which emerged from the research was known as the "Internet." The system of protocols which was developed as part of this research effort became known as the TCP/IP Protocol Suite, after the two initial protocols developed: Transmission Control Protocol (TCP) and Internet Protocol (IP).

In 1986, the U.S. National Science Foundation (NSF) initiated the development of the NSFNET which, today, provides a major backbone communication service for the Internet. In 1989, the Internet system began to integrate support for other protocol suites into its basic networking fabric. The present emphasis in the system is on multiprotocol internetworking, and in particular, with the integration of the Open Systems Interconnection (OSI) protocols into the architecture.

Both public domain and commercial implementations of the roughly 100 protocols of TCP/IP protocol suite became available in the 1980's. During the early 1990's, OSI protocol implementations also became available and, by the end of 1991, the Internet has grown to include some 5,000 networks in over three dozen countries, serving over 700,000 host computers used by over 4,000,000 people.

2.2 COMPONENTS OF THE INTERNET [2]

- **WORLD WIDE WEB**

The World Wide Web (abbreviated as the Web, WWW, or W3) is a system of Internet servers that supports hypertext to access several Internet protocols on a single interface Almost every protocol type available on the Internet is accessible on the Web. This includes e-mail, FTP, Gopher, Telnet, and Usenet News. In addition to these, the World Wide Web has its own protocol: Hyper Text Transfer Protocol, or HTTP.

- **E-MAIL**

Electronic mail, or e-mail, allows computer users to exchange messages locally or worldwide Each user of e-mail has a mailbox address to which messages are sent. Messages sent through e-mail can arrive within a matter of seconds.

- **TELNET**

Telnet is a program that allows you to log into computers on the Internet and use online databases, library catalogs, chat services, and more. To Telnet to a computer, you must know its address. This can consist of words (au3.au.ac.th) or numbers (168.120.10.13).

- **FTP**

FTP stands for File Transfer Protocol. This is both a program and the method used to transfer files between computers on the Internet.

- **ARCHIE - THE SEARCH PROGRAM OF FTP**

Archie functions as a catalog of FTP sites. Archie is a program that searches all the FTP sites on the Internet that are on its master list, and stores the filenames in a central database.

2.3 What is TCP/IP? [3]

TCP/IP is a set of protocols developed to allow cooperating computers to share resources across a network. It was developed by a community of researchers centered around the ARPAnet. Certainly the ARPAnet is the best-known TCP/IP network. However as of June, 87, at least 130 different vendors had products that support TCP/IP, and thousands of networks of all kinds use it.

The Internet is a collection of networks, including the ARPAnet, NSFnet, regional networks and a number of military networks. The term "Internet" applies to this entire set of networks. The subset of them that is managed by the Department of Defense is referred to as the "DDN" (Defense Data Network). This includes some research-oriented networks, such as the Arpanet, as well as more strictly military ones. All of these networks are connected to each other. Users can send messages from any of them to any other, except where there are security or other policy restrictions on access. Officially speaking, the Internet protocol documents are simply standards adopted by the Internet community for its own use.

The applications programs such as mail, TCP, and IP, as being separate "layers", each of which calls on the services of the layer below it. Generally, TCP/IP applications use 4 layers:

- an application protocol such as mail
- a protocol such as TCP that provides services need by many applications
- IP, which provides the basic service of getting datagrams to their destination
- the protocols needed to manage a specific physical medium, such as Ethernet or a point to point line.

2.4 A BRIEF HISTORY OF INTERNET IN THAILAND [4]

Some Thai students and visitors to the United States of America had been given Internet addresses but when they return to Thailand, not many continued to use their addresses because of the high cost of international telephone connection. In 1987, the Asian Institute of Technology (AIT) in Thailand entered into an agreement with the Department of Computer Science at the University of Melbourne in Australia to operate Internet email service on a regular basis. The Australian node would call AIT three times a day to send and collect mail.

In 1988, Prince of Songkhla University in the southern part of Thailand established an Internet node connected to Melbourne University a few times a day. Two dial-in telephone numbers were made available from 09:00 in the morning till 19:00 in the evening.

In 1991, Digital Equipment (Thailand) Ltd. acquired an Internet address for internal and research-related usage. No dial-in number was made available and user had to use the machine at the company.

A major breakthrough occurred in 1991 when Chulanlogkorn University became Internet gateway in Thailand. After sufficient testing, full operation was started in July 1992 with a 9600 bps leased line to Virginia, U.S.A. and later upgrades to 64 K line. The fees for the leased line with 25% educational discount from the Communications Authority of Thailand (CAT) were about 5.2 million baht per year (about US$ 468,000). Initially only one telephone line was made available but by 1993 twenty lines were accessible. The all day, all night and full Internet service at Chulalongkorn University were obviously much better than the email-only at AIT. Instead of waiting a day or so for the message to be routed through Australia, one could communicates as many times a day as necessary and desirable. One could use the "talk" command to enter into interactive communication. When calls for papers were received from the network, one could ask for and obtain clarification right way.

In January 1992, the National Electronics and Computer Technology Center (NECTEC) established the NECTEC E-mail Work Group (NWG). In February 1992, NWG established a network named ThaiSarn (Thai Social/scientific, Academic and Research Network) with a machine donated by IBM, two dial-in telephone lines available 24 hours a day for NWG connections. UUCP (UNIX-UNIX Copy) was made hourly with Thammasat University and Prince of Songkhla University, and international connection with Australia through AIT three times a day. The service was later upgraded to included six dial-in telephone lines and 24 hours per day international connection through Chulalongkorn University. Then in September 1993, NECTEC became the second gateway from Thailand and it was connected toVirginia,U.S.A. by a 64 K leased line.

In January 1992, Thammasat University (TU) Information Processing Institute for Education and Development (IPIED) also register as an Internet node. One dial-in telephone number was made available 24 hours a day.

The Faculty of Engineering at King Mongkut's Institute of Technology Ladkarbang started experimenting with Internet in mid 1992 connected to at Thammasat. At the beginning, only about 40 users were approved. Later the Computer Research and Service Center which serves all the faculties established a central node for Ladkrabang. By October 1993, about 500 Internet addresses had been given.

Digital Equipment (Thailand) joined ThaiSarn in January 1992 but was later disconnected because commercial organization was not allowed to use educational Internet in Thailand. Prince of Songkla University and AIT joined ThaiSarn in 1992 but AIT later installed a direct leased line to Chulalongkorn University.

2.5 Work previous done

The work previous done that is background similar to my thesis topic which about Analysis Internet Traffic are:

- Global Internet Traffic Model [5].
- Generative Workload Models of Internet Traffic [6].
- Time Series Models for Internet Traffic [7].

For this three papers I will mention about the measurement and how they model the Interne Traffic

2.5.1 Global Internet Traffic Model [5]

The main focus of this topic is to develop a methodology to measure the demand for the Internet network within their countries. They attempt to develop their methodology based on existting time series information about traffic flows among different countries. The primary aim of this study is to understand the current and future traffic transactions among different countries in the world. The model will explain both inbound and outbound traffic among different countries.

The Model

The Internet network demand can be measured in two dimensions. One is how long users are actively connected with the Internet and second is how much of the network capacity they are using. Since the Internet is based on a packet-switching system, the duration of time connected with the Internet much depends on the efficiency of the movement of packets between different IP addresses.

They first concentrate on analyzing the demand for network capacity. Each packet in the Internet carries a certain number of bytes worth of information in it. Therefore, one way to estimate the network demand is to estimate the demand for the movement of the number of bytes within a specific time period among different countries. This can be defined as the demand for use of network capacity between countries.

With the current availability of Internet related data, it is difficult to estimate any standard econometric demand model to explain the current and future traffic flows among different countries in the world. Therefore, they are developing some methodology to explain current and future expected traffic flow subject to the constraint of data availability. First, they develop a descriptive model based on some simplified assumptions to explain the current flow of traffic and then use that methodology to predict the future traffic flow among different countries.

To develop the methodology to measure the demand for traffic transactions that in turn will explain the demand for network capacity, the following assumptions are made:

They assume that the world consists of several countries among which only two countries: country-1 and country-2 - exchange information through Internet. Their aim is to develop a formal model, which will allow them to estimate the present and future traffic flow between these two countries. This model then can be easily extended for more than two countries.

From their previous experience, the network based telephone services has long been recognized as a case in which important externalities exist in the demand functions of individual consumers. Similar externalities are likely to exist in the demand function of individual Internet users. Based on this externalities theory, they can assume that the flow of traffic from one country to another country is much dependent on the number of available hosts/sites within the country of origin and the number of hosts/sites available in the country of destination. This assumption indirectly implies that the information available in all the sites are equally important to relevant Internet users. For example, if country-1 has less hosts/sites than country-2, it is likely that due to network externality theory, country-1 will have proportionately more international transactions per user than country-2. Country-2 on the other hand will have relatively more domestic transactions per user than international transactions per users.

Methodology

Once we know the total traffic generated by each country, we can distribute the traffic between domestic and international traffic proportional to the number of users and the sites in each country. Possible inflow and outflow of traffic from one country to another can be described based on the information about the number of users, number of sites and the behavior of users in different countries. If the number or users as well as the number of sites of a country represent a very small share in the Internet world, then it is likely that this country will receive more traffic from the rest of the world than it sends to others. One point is important to remember at this point is that the inbound traffic for one country is the outbound traffic for some other countries. Therefore, total international inbound traffic is always equal to total international outbound traffic. This is true in domestic arena also. So any traffic distribution methodology must satisfy this condition. In case of 2-country situation, it implies that total International traffic of country-1 (includes inbound and outbound traffic) must be equal to total international traffic of country-2. This will not be true if we extend our methodology to apply for more than 2 countries. In that case total international inbound traffic of all countries must be equal to total international outbound traffic of all countries in our defined Internet world.

The Problem regarding in this method is the difficult of obtaining the information about current and historical records of number of users and number of sites by country. Therefore, they propose in this paper an alternative method of estimation, which is described below. This alternative method relies on the assumption that the number of users or the number of sites in any country is positively related to the number of hosts in that country. It also implies that the users in any country have identical behavior and sites in all countries are equally attractive to all users in the world.

Measurement

The methodology explained above will provide an estimate of the current traffic flows among different countries. However, to predict the future traffic flows among different countries, we need to predict the number of hosts by country and total traffic generated by all countries. They can predict the total number of hosts and Average traffic per host by developing the time series forecasting model using the available time series data on those variables and then estimate the total world Internet traffic by multiplying the total number of hosts by average traffic per host. They also have the information about number of hosts by country. Therefore, once they estimate the total traffic, they can distribute the traffic flows among different countries assuming that relative distribution of number of hosts among different countries will remain same in future. Only the level of number of hosts will change due to growth.

To implement the methodology described in the demand model, the following designs and assumptions are used. They include all the major countries in the world, which are currently using Internet technology, which are responsible for almost 90% of Internet traffic. Selected countries are segmented into 7 groups: US, Canada, Australia, Europe, Asia, South America and Africa. Each segment mentioned above includes most of the countries, which are relevant for estimating the expected demand for near future.

They first developed the model using NSFNET traffic history (March, 1991-Dec, 1994) provided by Merit Inc. and the history of number of hosts (July, 1981 to July, 1996) produced by Network Wizards. Since NSFNET traffic mainly represents traffic generated within the US or between the US and other countries and systematic data is not available to explain the traffic patterns among the rest of the countries in the world, they used other existing information to obtain an estimate of the traffic transactions among countries outside the US.

No systematic statistics regarding traffic for countries outside NSFNET is available. Therefore they estimate those traffic flow based on available information. The following methodology is used to estimate the traffic flow: they estimate the average traffics generated per host in US and combine that information with the information about hosts for different countries to interpolate the traffic pattern among countries outside the US.

So predict future possible traffic of the Internet, they combine both the information about NSFNET traffic history and history of host counts by country. NSFNET time series data explains the partial traffic, which goes through NSFNET backbone only. This time series data extends until the beginning of 1995 which does not fully reflect the exponential growth in traffics of recent era due to the revised architecture of NSFNET and development of other commercial backbones. Therefore, any prediction of traffic based on this time series might be downward biased. Therefore, they used the time series data of total number of hosts for different countries which is available until the most recent months (July. 1996) capturing the recent trends in Internet use. Based on this time series data, they predict the expected future number of hosts. An estimate of traffic per host is obtained using historical information about traffic and hosts related to NSFNET and combine that information with the predicted hosts figure to extrapolate some lower bound of the possible future traffic flows among different countries around the world.

2.5.2 Generative Workload Models of Internet Traffic [6]

This paper presents the analysis of the World Wide Web (WWW) traffic. In this paper they have presented a hierarchical, generative approach for workload modeling of WWW-applications. They have identified four hierarchical layers, bridging the gap between the user level of GET/POST methods. The actual physical characteristics of the system as well as the application oriented view. Thus, the analyst is able to investigate both, changes in the user behavior and the effects of changes in the system characteristics. By using Probabilistic Attributed Context Free Grammar (PACFG) as a model for translating from a user oriented view of the workload (namely the conversations made within WWW browser windows) to the methods submitted to the Web servers (respectively to a proxy server). For this method they are able to increase the expressiveness of the grammar while the control set will ensure, that the workloads truly represent the user and system behavior. The sentential forms give a representation of all the necessary details for capturing the state of the system at any instance in time, while the timing attributes provide the quantitative information.

The Model

For this paper they modeling WWW traffic by use the Probabilistic Attributed Context Free Grammar (PACFG) which is a 3-tupleG_a = {G,A,Q } with G as the regular grammar, G = $\{V_N, V_T, P, S\}$.Here, V_N and V_T are a set of production rules, and S is the start symbol. A is a set of attributes and Q is a set of probabilities associated with P

They consider a hierarchical system with n levels. At each level, the system supports a set of operations that represent by a non-terminal. Nonterminals in the n^{th} level of the hierarchy expand into a nonterminals in the $(n-1)^{th}$ level. Production rules are used for representing this. At level n, the number of classes of operations is represented by K_n.To decide on which of the operations in a lower level to which an operation in a given level expands to, a set of probabilities are used. A non-terminal in level n and of type I can either always go to ε. Or there are a set of production rules mapping it onto units of the lower level.

Attributes are associated to each non-terminal, denoting the start time and end time of the operation ($start(V_{NT})$, $end(V_{NT})$) with $time(V_{NT}) := end(VNT) - start(V_{NT})$. Start and end times will depend on the order in which the production rules are applies and are derided from start/end times of terminals and non-terminals at higher /lower levels. Start times are always inherited, end times will always be synthesized, thus guaranteeing an evaluation free of cyclic dependencies. The time attributes of the terminals are defined analogously, but their duration $time(V_T)$ is parameter to be estimated, thus the end time is given by $end(V_T) := time(V_{NT}) + start(V_{NT})$.

They define the workload model as a PACFG with

$$WWWLoad = \{\{\{WL, B_i, W_{ij}, c_{ij}, H_{ij}, F_{ij}, G\}, \{l, s, r, \beta, \omega, \varepsilon\}, \{P\}, WL\}, \{A\}, \{Q\}\}$$

Where

G is a non-terminal denoting the method GET

t is the user think time

Measurement

To estimate the number of GETs within an http connection which can be obtained by analyzing the log file of a proxy server. It show for each GET the corresponding reference to the URL initially retrieved in the http conversation.

The interarrival time at the browser level determine the time at which users will start a new browser. The arrivals will be bursty according to the time of the day. For a characterization, all these aspects have to be take into account, leading to the conclusion, that empirical distributions might fit best to characterize this behavior.

The user think time represents the time that user needs to process the requested information. To characterize this time by a histogram representing an empirical distribution of user think times. This empirical distribution can be derived from measurements of user sessions (logging the actions of the user on a particular machine).

2.5.3 Time Series Models for Internet Traffic [7]

The last topic is Time Series Models for Internet Traffic. This paper is about data traffic sequences from two campus FDDI rings, an Ethernet, two entry/exit point of the NSFNET, and sub-sequences belonging to popular TCP port numbers on one of the FDDI rings indicated from these traces can be modeled as Multiplication Auto-Regressive Integrated Moving Average model (ARIMA).

A sequence of steps leading through

- parameter estimation
- generating the distribution of the varieties
- forecasting tail percentiles
- synthetic generation of non-negative integer sequences is presented

the data indicates that parameter estimates drift slowly with time and may need to be re-computed periodically for accurate forecasts. The forecasting algorithm has potential application in dynamic resource allocation.

The Model

ARIMA models have typically been applied with Gaussian variates. However, this is not a necessity. If one is willing to adopt a non-linear least squares algorithm for parameter estimation, one can compute the variates of the distribution and obtain their tail percentiles directly from the computation using compute power of current machines where maximum likelihood based methods become intractable. There are of course limitation of such an approach: no longer are the standard acceptance/rejection tests based on known distribution forms available. The analyst does have plot on the autocorrelation function (ACF) of residuals to point out the potential model inadequacies.

The distribution of the varieties can be used for forecasting tail percentiles of traffic data. Such a forecast is useful if the cost of overshooting the forecast is significantly higher than undershooting it. The algorithm may have potential application in dynamic bandwidth and buffer allocation strategies for connectionless servers. While it is not clear that approach will be adopted by the networking community, the key is that such a forecast can be efficiently achieved in many case.

Synthetic traffic is another application of interest and sensitive study of parameter estimates on a given network configuration or a new algorithm being tested. Preliminary results on generating such sequences indicate that noise suppression in the generation process is an important consideration. Partial results based on truncation and rounding with probabilities μ and $(1-\mu)$ indicate that the noise is indeed sufficiently damped.

Measurement

Traffic data that them studied were:

- Data on the San Diego FDDI ring.
- The NSFNET ENSS,s provided by Hans Werner Braun, San Diego Supercomputer Center.
- Ethernet data provided by Will Leland, Bellcore.

All of this data contain the Duration, Packets size and Model Order.

2.6 Little's Theorem

It is the general and useful theorem to find the number of customers in the system and the customer delay which are two important factors in Queuing system. Let

N = Number of customers in the system at steady state

λ = The steady-state arrival rate

T = The steady-state time average customer delay

It turns out that the above quantities N, λ and T are related by simple formula that makes it possible to determine one given the other. This result, know as Little,s Theorem, has the form $N = \lambda T$.

2.7 Queuing theory [8]

Queuing theory is the primary methodological framework to analyzing network delay.This delay is the sum of delays on each subnet link tranversed by the packet. Each link delay in turn consists of four components.

1. The processing delay between the time the packet is correctly received at the head node of the link and the time the packet is assigned to an outgoing link queue for transmission.

2. The queuing delay between the time the packet is assigned to a queue for transmission and the time it starts being transmitted.

3. The transmission delay between the times that the first and last bits of the packet are transmitted.

4. The propagation delay between the time the last bit is transmitted at the head node of the link and the time the last bit is received at the tail node.

The network delay often requires simplifying assumptions since more realistic assumptions make meaningful analysis extremely difficult. For this reason. It is sometimes impossible to obtain accurate quantitative delay predictions on the basis of queuing models. These models often provide a basis for adequate delay approximations, as well as valuable qualitative results and worthwhile insights.

There are several type of queuing system which can be categorized by using 3 parameters:

1. The first letter indicates the nature of the arrival process

    M stand for memoryless, which means a Poission process(i.e., exponentially distributed interarrival times.

    G stand for a general distribution of interarrival times.

    D stand for deterministic interarrival times.

2. The second letter indicates the nature of the probability distribution of the service times (e.g., M, G, and D stand for exponential, general, and deterministic distributions, respectively). In all cases, successive interarrival times and service times are assumed to be statistically independent of each other.
3. The last number indicates the number of servers.

Various queuing systems can be used to analyze the Internet traffic such as M/M/1, M/G/1 or G/G/1. The most suitable queuing system for the Internet traffic can be found based on the measurement results of the traffic.

After the most suitable queuing system is selected the average waiting time in the queue and the average number of customer waiting in the queue are calculated. Then the result from calculation and from using the Opnet simulation program are compared.

- The M/G/1 System :

It is Queuing system with a single-server where customers arrive according to a Poisson process but the customer service times have a general distribution. This queuing system can apply to use with M/D/1 system because general distribution can apply to use with deterministic distribution.

- An Upper Bound for the G/G/1 system

Consider the G/G/1 system, which is the same as M/G/1 except that the interarrival times have a general rather than exponential distribution. We continue to assume that the interarrival times and service times are all independent.

- D/D/1 system

It is Queuing system with a single-server where customers arrival statistic and the customer service times have general distribution. This system can apply from G/G/1 system.

CHAPTER 3. MEASUREMENTS

This chapter presents the measurement results of Internet Protocol (IP) packets from the university. There are two class of packets :

Class B : IP = 168.120.x.x and

Class C : IP = 202.6.100.x

IP = 202.6.101.x

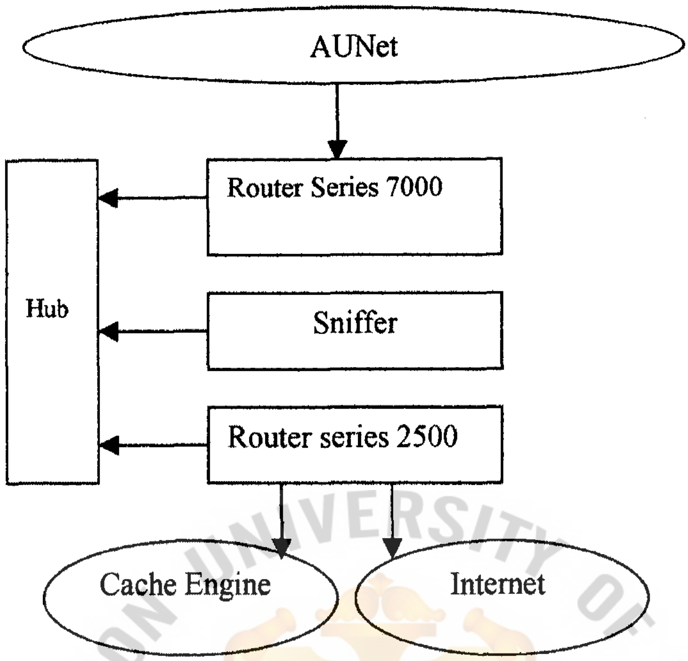
The packets information is captured using Sniffer network analyzer. The results from measurement are interarrival times and packet sizes, which are two important factors used to find the arrival statistic and service statistic of the network. Then these two factors are used in calculation and simulation

(using Opnet) to find the total waiting time in queue and the total number of customers in queue.

The Sniffer Network Analyzer consists of two main software components: the Sniffer analyzer application and the Monitor application. The analyzer application allows you to capture the traffic of network with you can filter only Protocol you want to measure and monitoring in the real time traffic. The available Protocol for the analyzer are TCP/IP, IBM, Novell, DECNet, Apple Talk and Oracle.

The measurement is done at 6th floor of Q building where the gateway connecting to outside network is located. Time to measure is every 1 hours from 8:00 a.m. to 5:00 p.m. in one week.

The connection of the Sniffer network analyzer to network is show below.



Following is the example of the measurement results

Table3.1 The results of measurement from Sniffer network analyzer

SUMMARY	Delta T	Bytes	Destination	Source	Summary
M 1		1514	[131.228.165...	mail.au.ac.th	IP
2	0.00007	60	[203.148.248...	[168.120.8.17]	IP
3	0.00074	60	chat.msn.com	[168.120.13.68]	IP
4	0.00018	60	[209.75.126.6]	AMPEEKA	IP
5	0.00047	60	sun.cc.au.ac.th	[203.148.231...	IP

Summary : Show packet Number.

Delta T : Show arrival time of packet.

Bytes : Show size of packet.

Destination : Show the destination of packet.

Source : Show source of packet.

Summary : Show Protocol of packet.

After get this results I will select only the IP address from ABAC, which are:

Class B :

Modem IP = 168.120.10-13.xxx

IRC IP = 168.120.16.250

Class C :

au1.au.ac.th IP = 202.6.100.1

au2.au.ac.th IP = 202.6.100.2

au3.au.ac.th IP = 202.6.100.3

KSC IP = 202.6.101.202

After the data is processed, the following result is achieved.

Table 3.2 The analyzed results

Delta	Byte
0.00014	60
0.00059	60
0.00006	60
0.00082	82
0.00007	70
0.00006	59
0.00150	60
0.00097	60
0.00006	60

Then a computer program called Crystal Report (an application in Visual Basic) is used to group the same number and then count the repetition. The result is show below.

Table 3.3 The final analyzed results

Delta	No. of Repeating
0.00001	4
0.00002	66
0.00003	90
0.00004	654
0.00005	8,204
0.00006	28,735
0.00007	24,721
0.00008	7,761
0.00009	7,020

Table 3.4 The final analyzed results

Bytes	No. of Repeating
60	12,960
61	94
62	816
63	6
64	17
65	290
66	607
67	425
68	55

Now the repeating number of intearrival time and packet size are presented.

From the queuing theory there are three types of arrival statistic which are the Memoryless interarrival times are exponentially distributed , G stands for a general distribution of interarrival times, D stands for deterministic interarrival times. The queuing theory of the service statistic is same as arrival statistic which are M, G and D stand for exponential, general, and deterministic distributions of service time. So the purpose of this topic is showing which type of distribution is suit for arrival statistic and service statistic in ABAC network.

Next, the arrival and the service statistic can be found by comparing the measurement of interarrival time in ABAC network with the Probability Density Function (pdf) of some distribution.

3.1 To find the arrival statistic :

In the first group of graphs below are present the measurement data from Assumption University network traffic and data from Probability Density Function (pdf) of the Exponential distribution. In the first group I compare the results with the exponential distribution because it is one on the three distribution in queuing system which use to find the arrival statistic and the formula is

$$P(\tau_n) = \lambda e^{-\lambda\tau_n}$$

where

τ_n is the interarrival time for n is positive number and independent of another.

λ is the arriving rate

For example the arrival rate on Monday at 8:00 a.m. equal to 6815 frames/sec so the pdf of exponential distribution is

$$P(\tau_n) = 6815 \times e^{(-6815 \times \tau_n)}$$

which show in the pink graph

The graphs below are the comparison of arrival statistic between the measurement results and the Probability Density Function (pdf) results at different time.

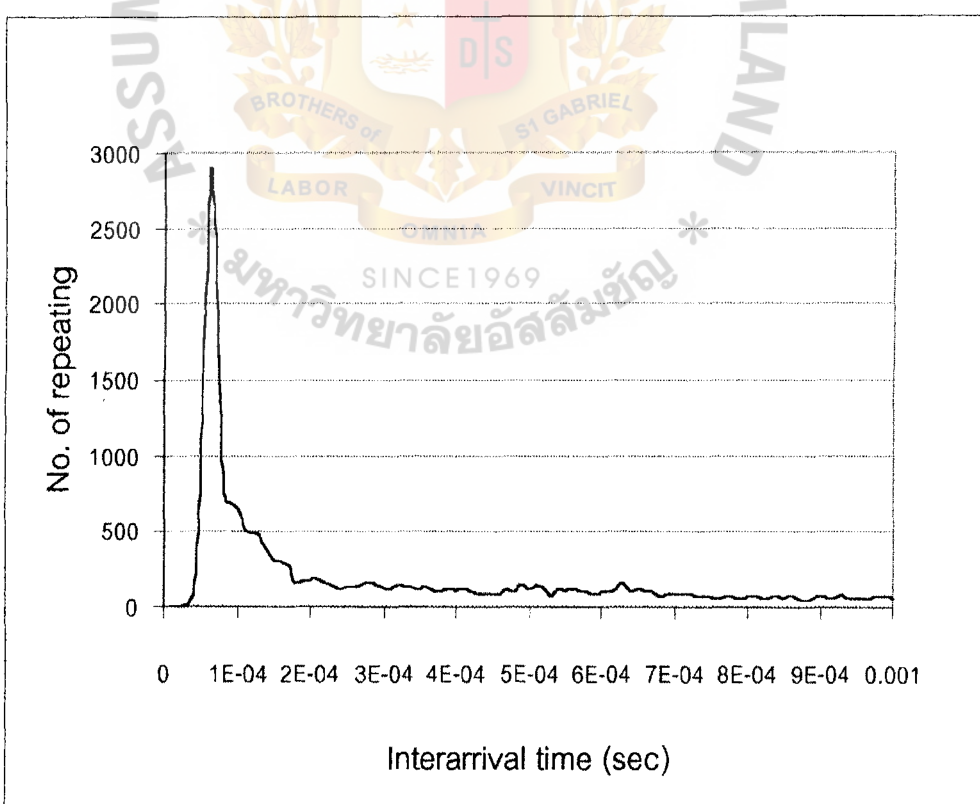


Figure 3.1 The arrival statistic from measurement at 8:00 a.m. on Monday

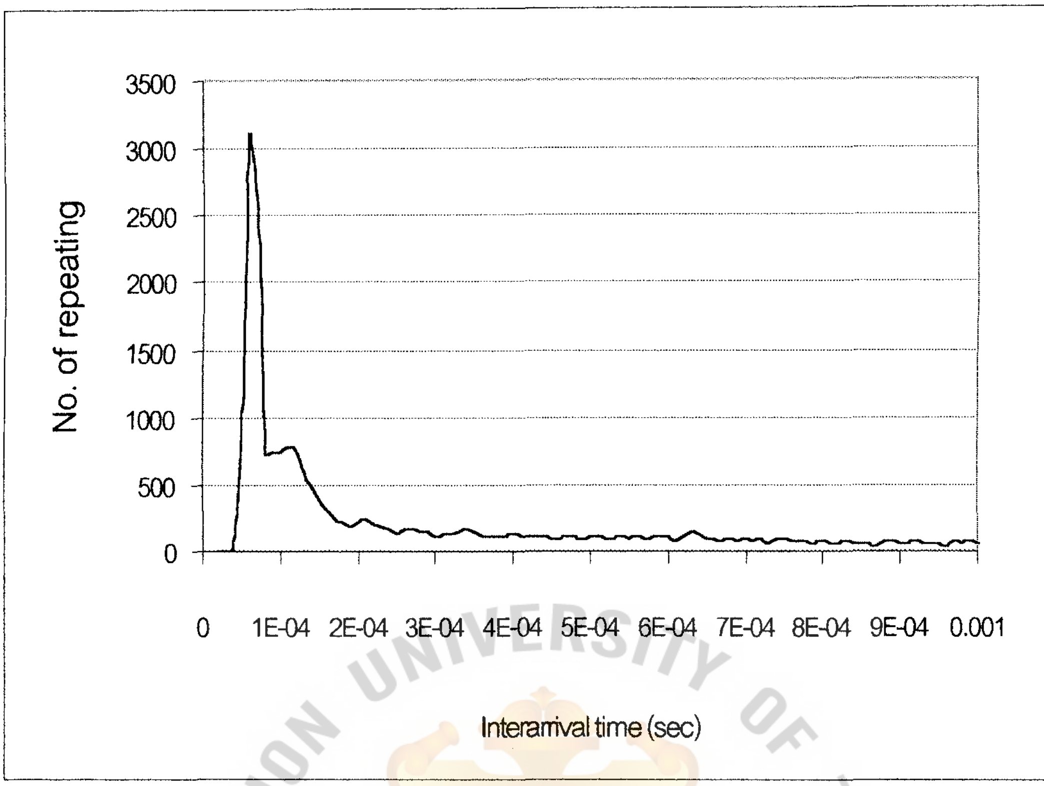


Figure 3.2 The arrival statistic from measurement at 9:00 a.m. on Monday

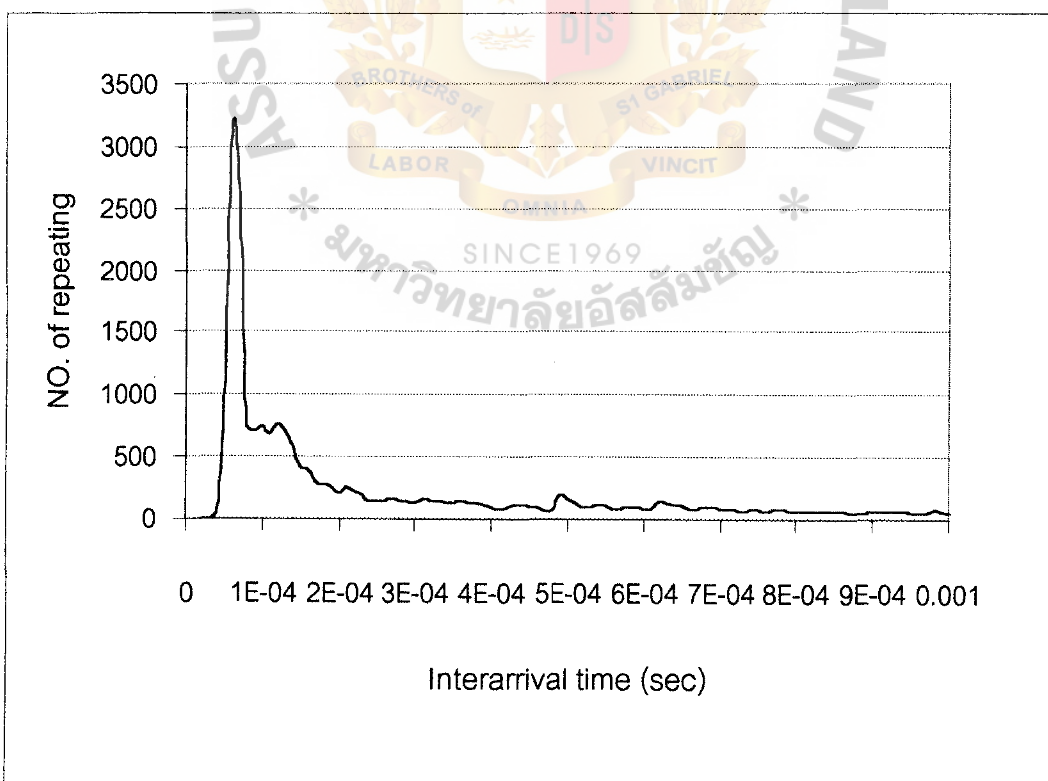


Figure 3.3 The arrival statistic from measurement at 10:00 a.m. on Monday

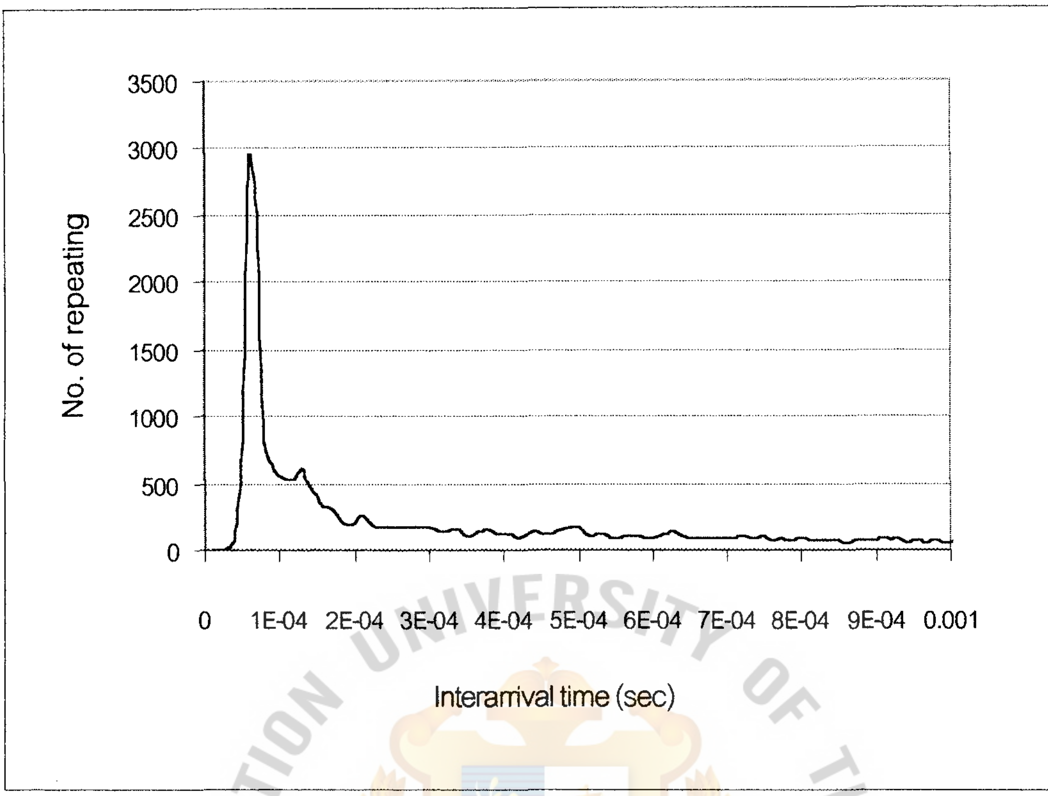


Figure 3.4 The arrival statistic from measurement at 11:00 a.m. on Monday

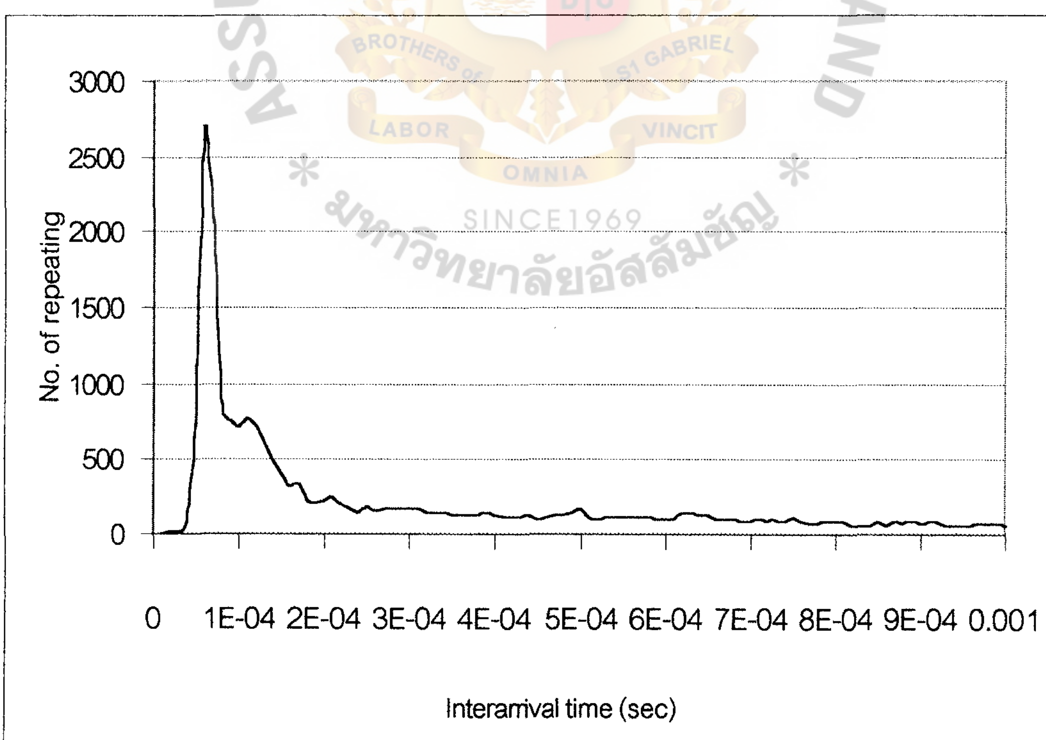


Figure 3.5 The arrival statistic from measurement at 12:00 a.m. on Monday

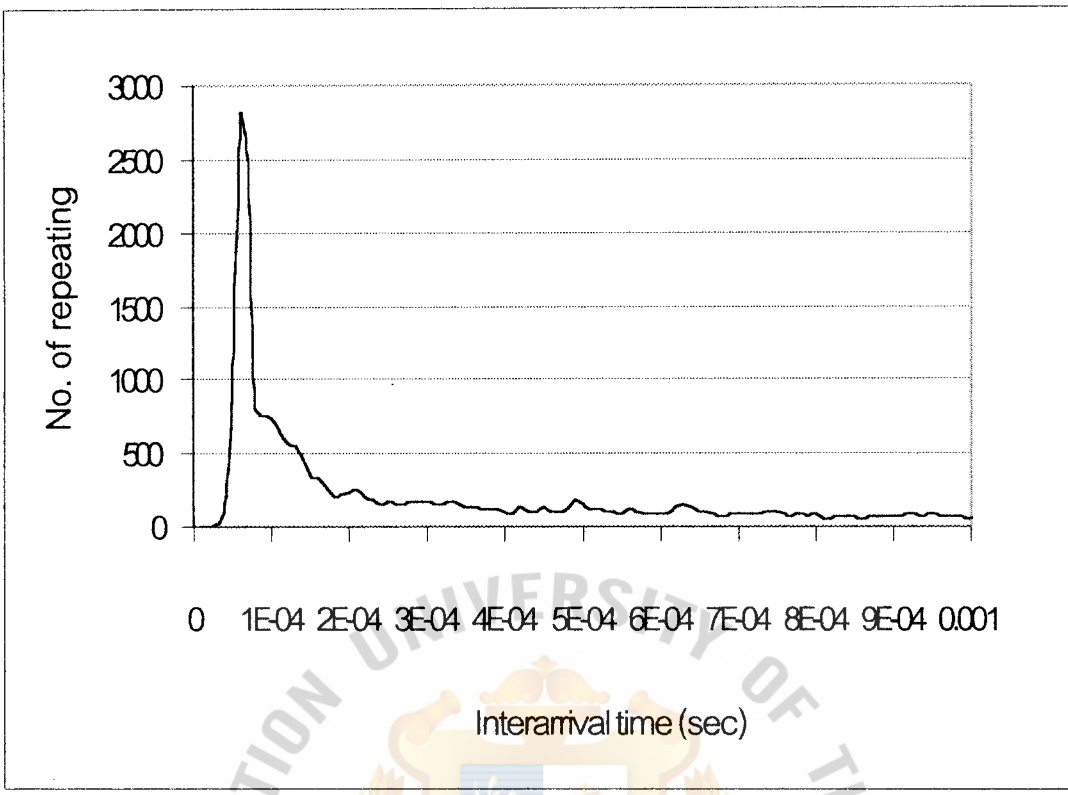


Figure 3.6 The arrival statistic from measurement at 1:00 p.m on Monday

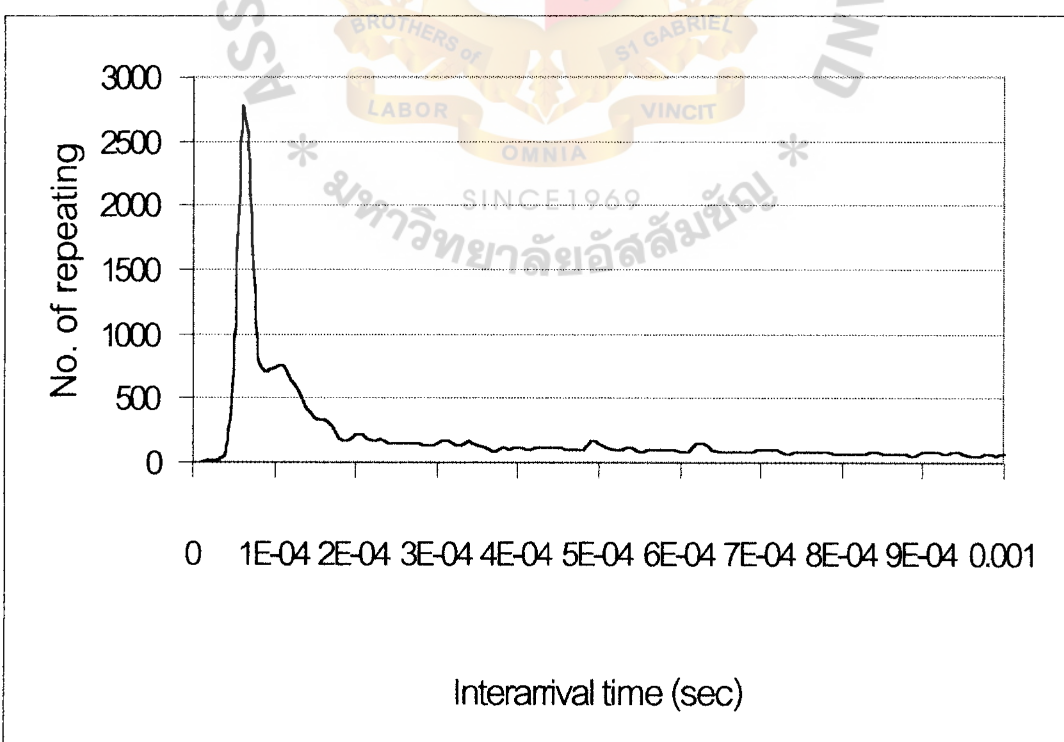


Figure 3.7 The arrival statistic from measurement at 2:00 p.m on Monday

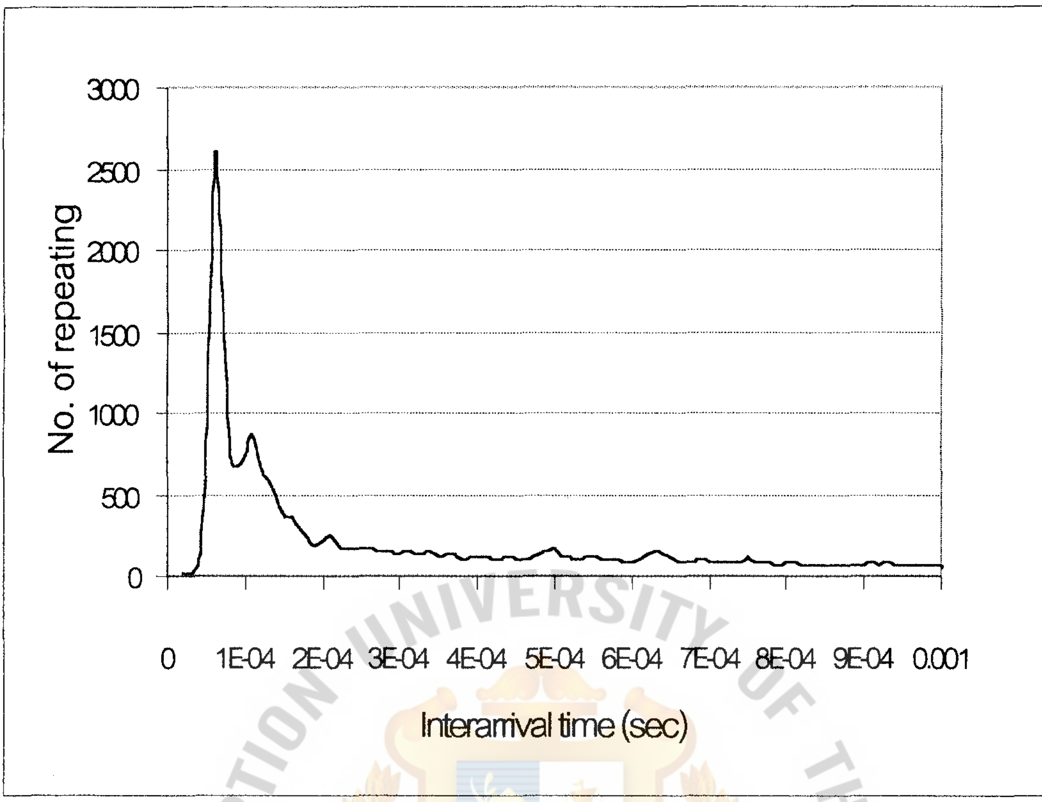


Figure 3.8 The arrival statistic from measurement at 3:00 p.m. on Monday

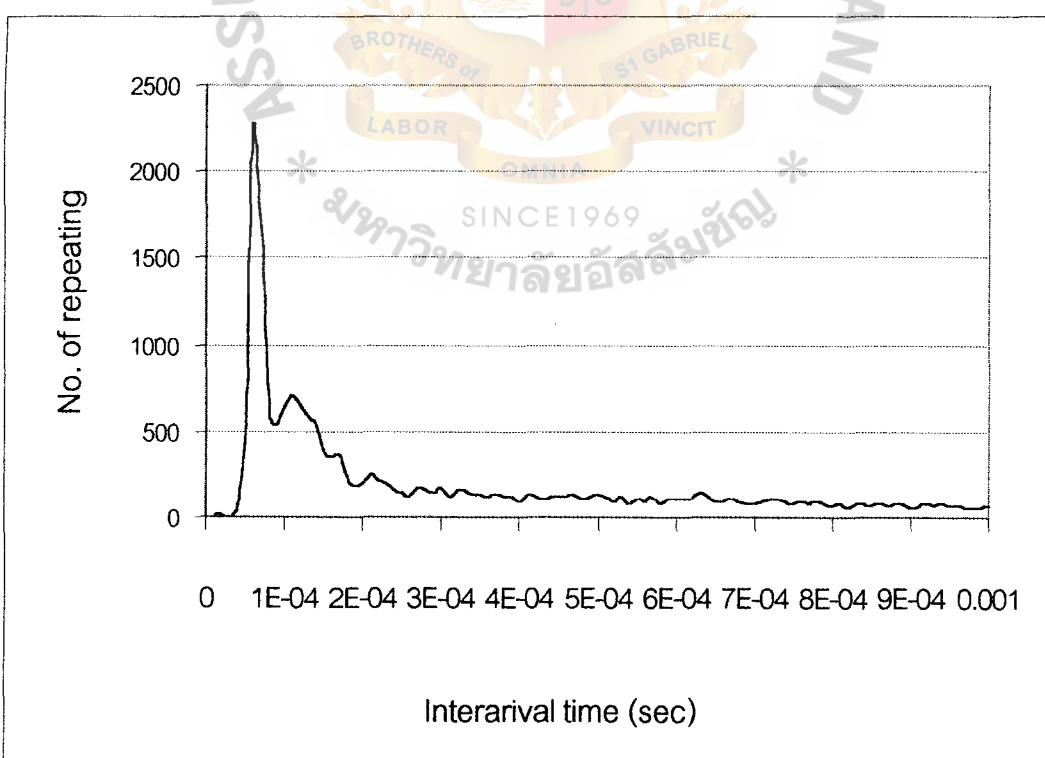


Figure 3.9 The arrival statistic from measurement at 4:00 p.m on Monday

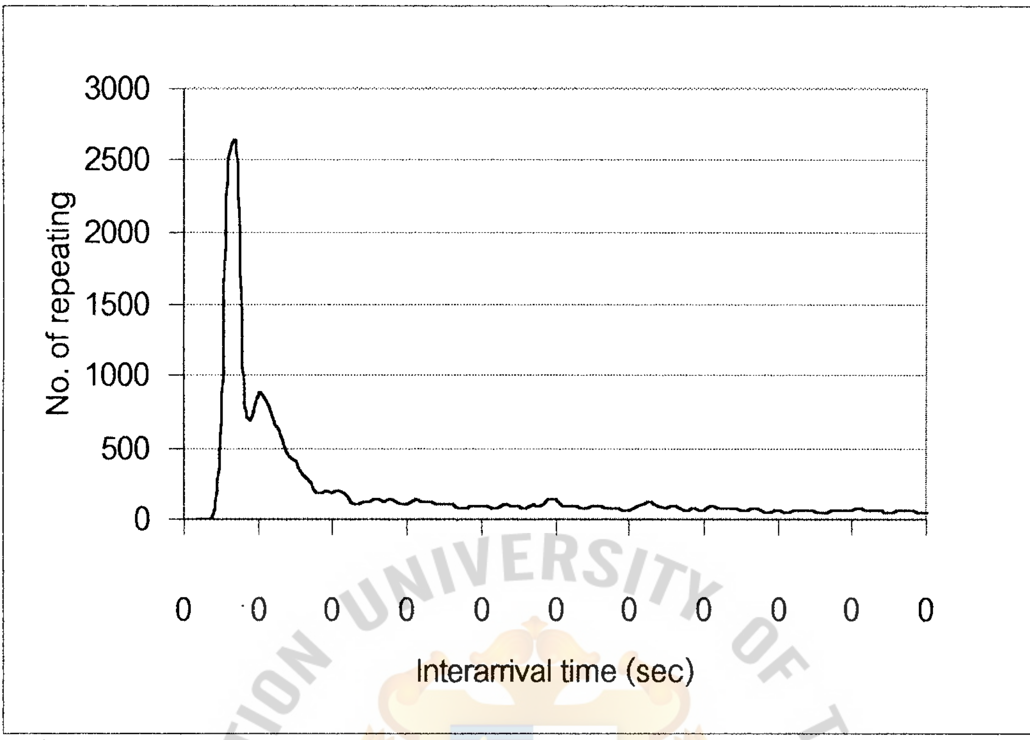


Figure 3.10 The arrival statistic from measurement at 5:00 p.m on Monday

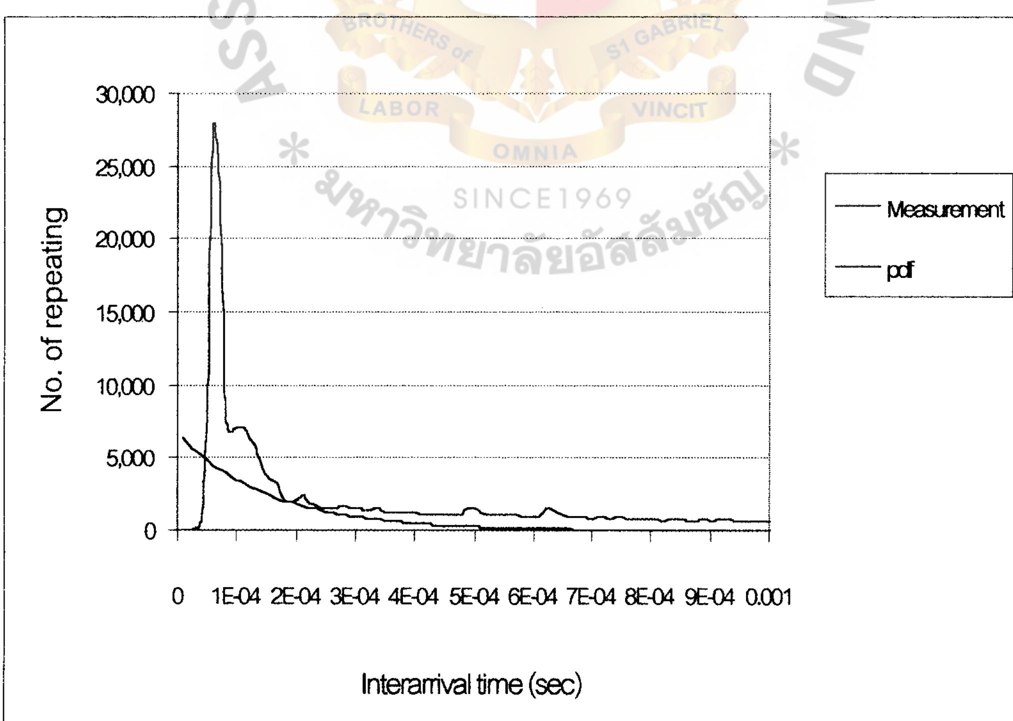


Figure 3.11 The arrival statistic between measurement and pdf result on Monday

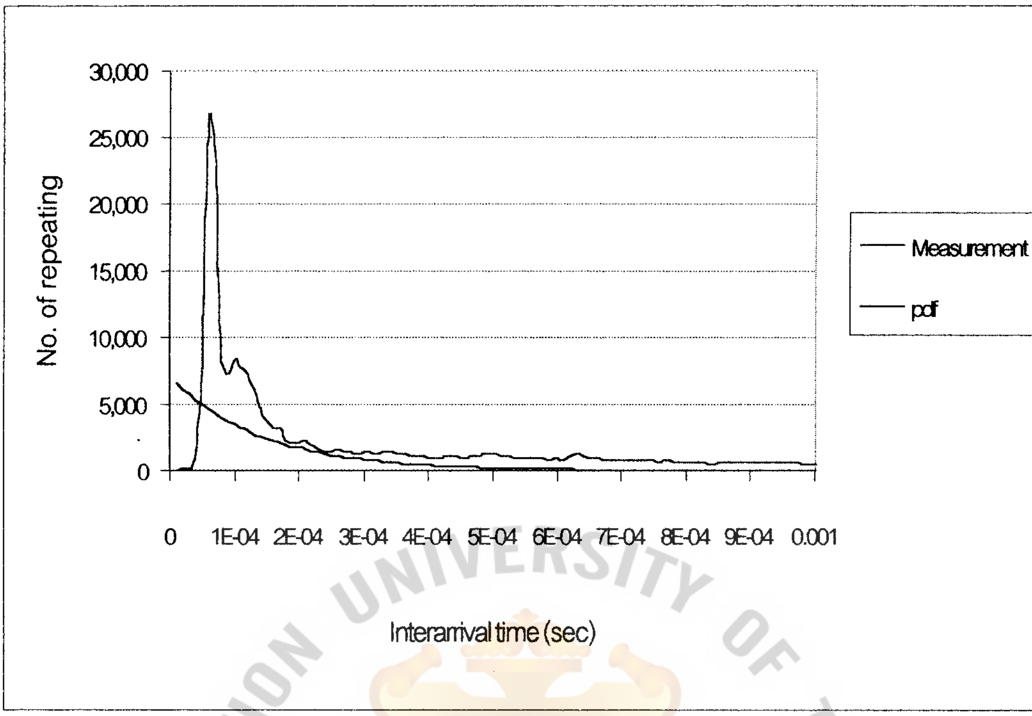


Figure 3.12 The arrival statistic between measurement and pdf result on Tuesday

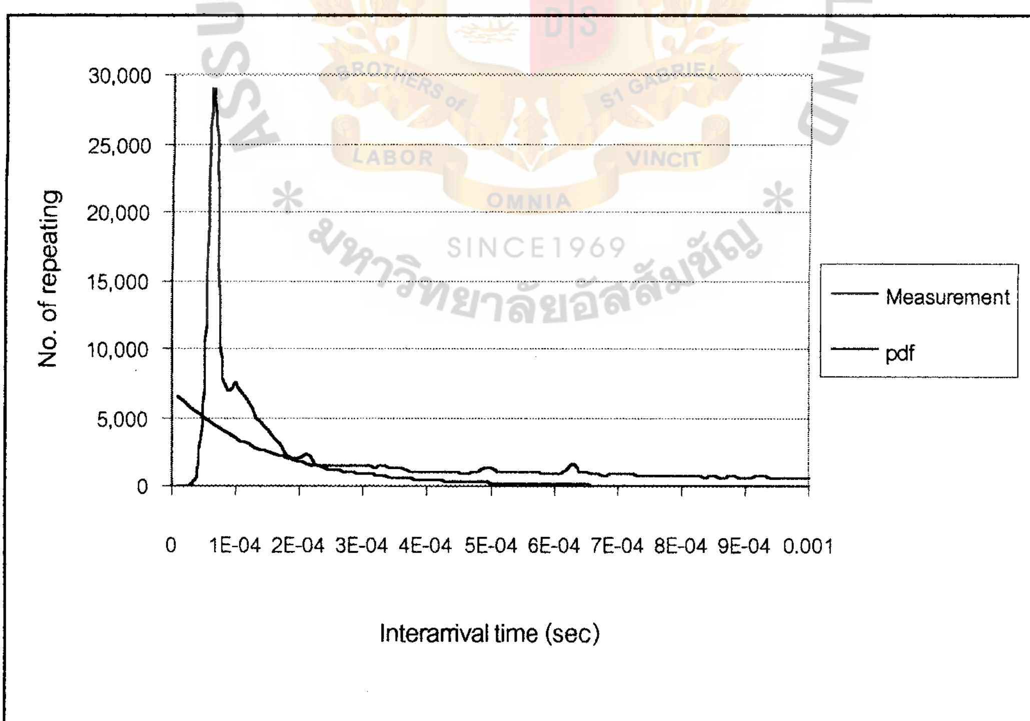


Figure 3.13 The arrival statistic between measurement and pdf result on Wednesday

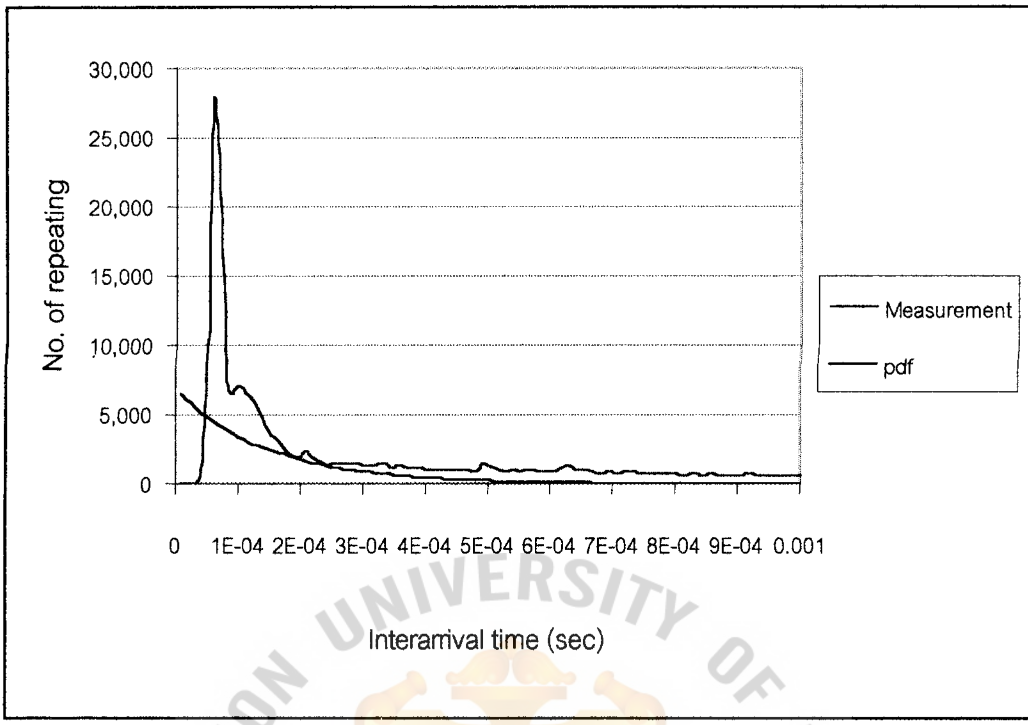


Figure 3.14 The arrival statistic between measurement and pdf result on Thursday

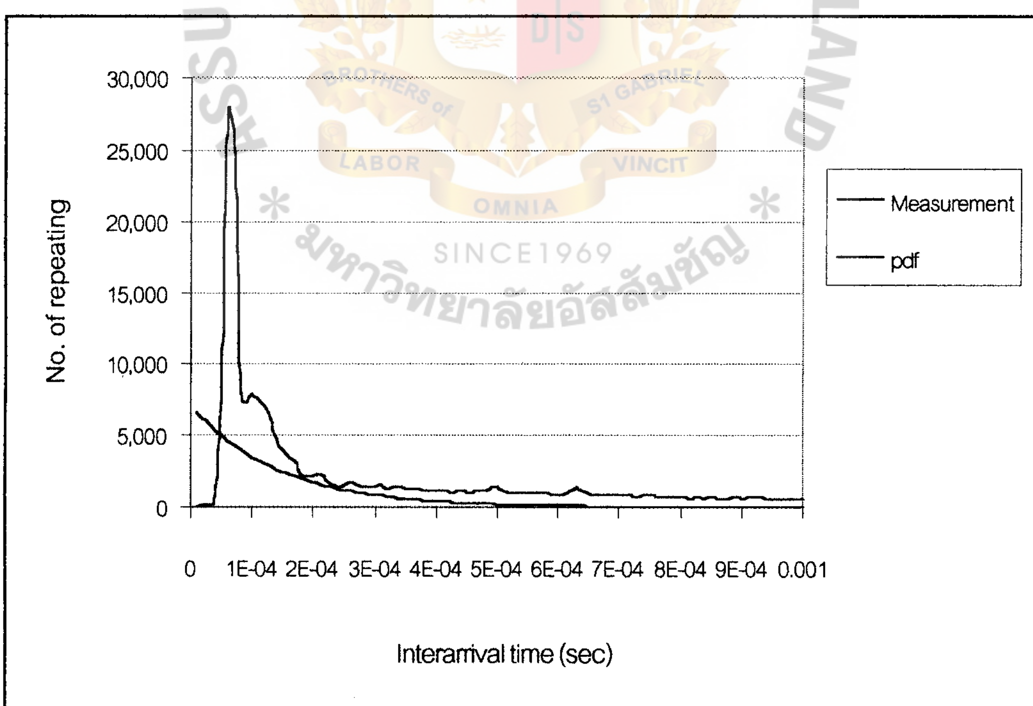


Figure 3.15 The arrival statistic between measurement and pdf result on Friday

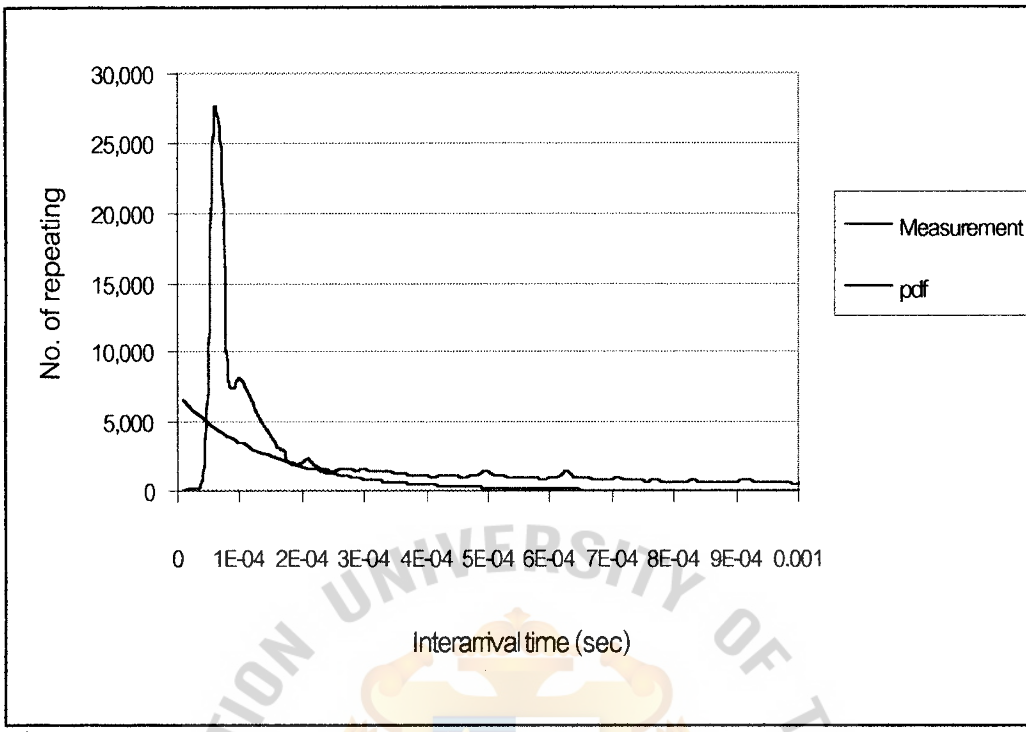


Figure 3.16 The arrival statistic between measurement and pdf result on Saturday

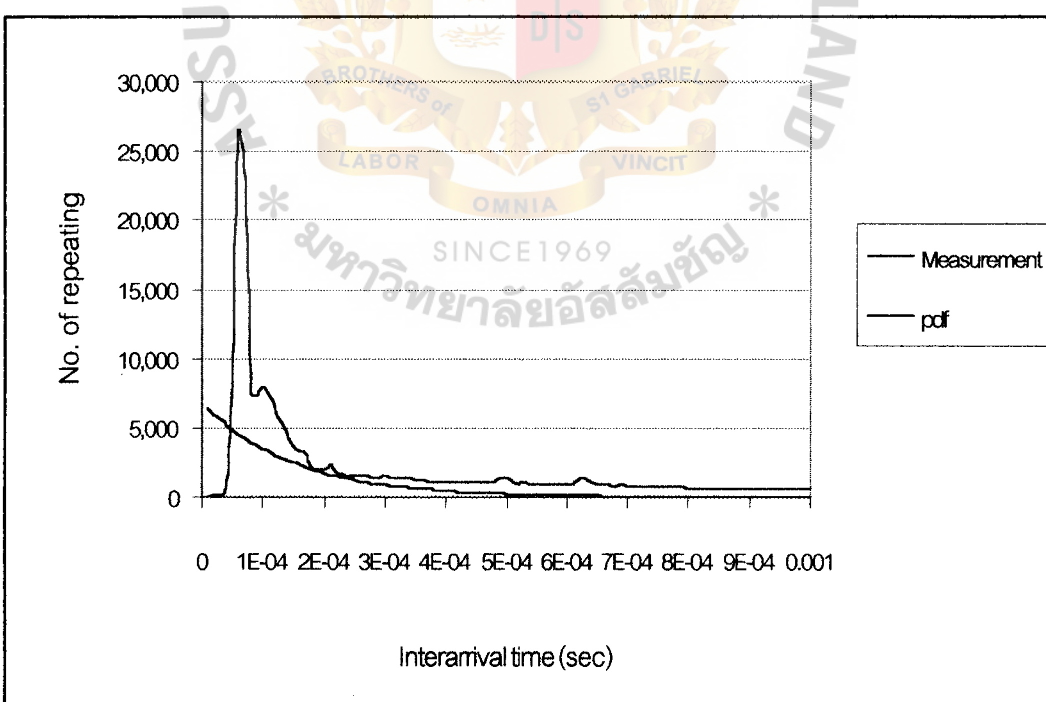


Figure 3.17 The arrival statistic between measurement and pdf result on Sunday

The graphs below is the comparison between the data from measurement from Assumption University network traffic and deterministic distribution in one week.

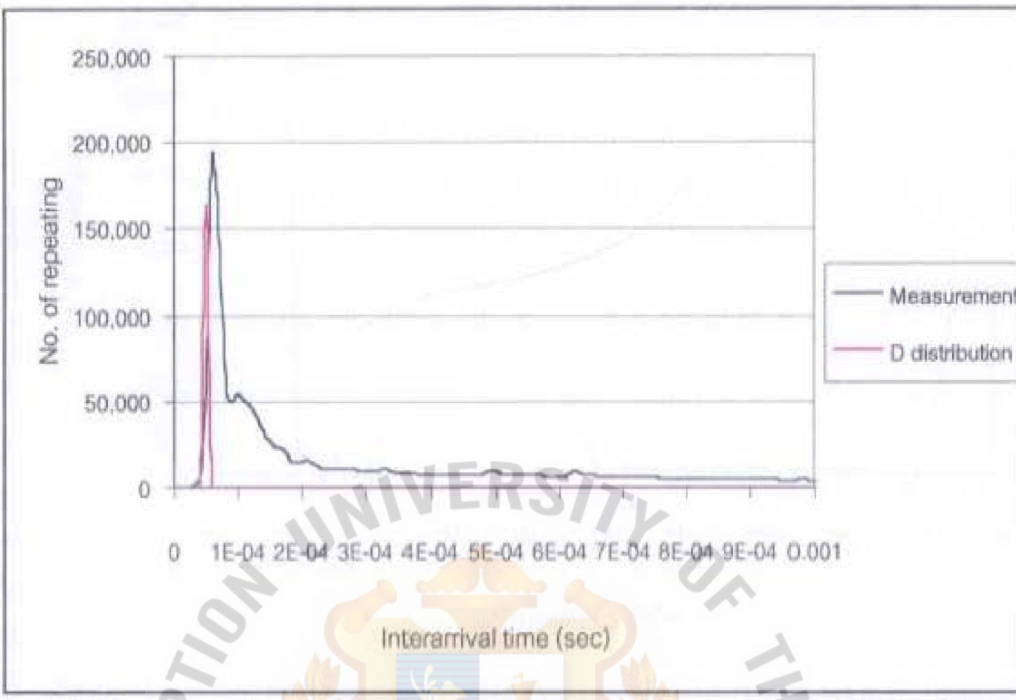


Figure 3.18 The comparison between measurement and deterministic distribution in one week.

3.2To find the service statistic

To find the service statistic which present by using graph of packet :

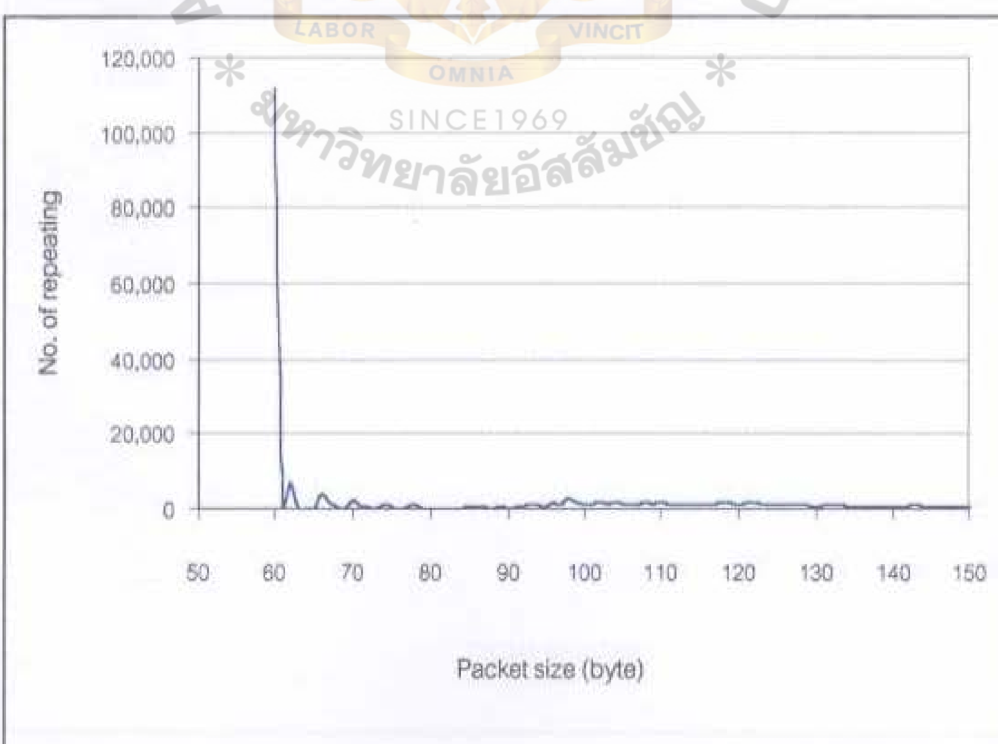


Figure 3.19 The graph of packet size on Monday

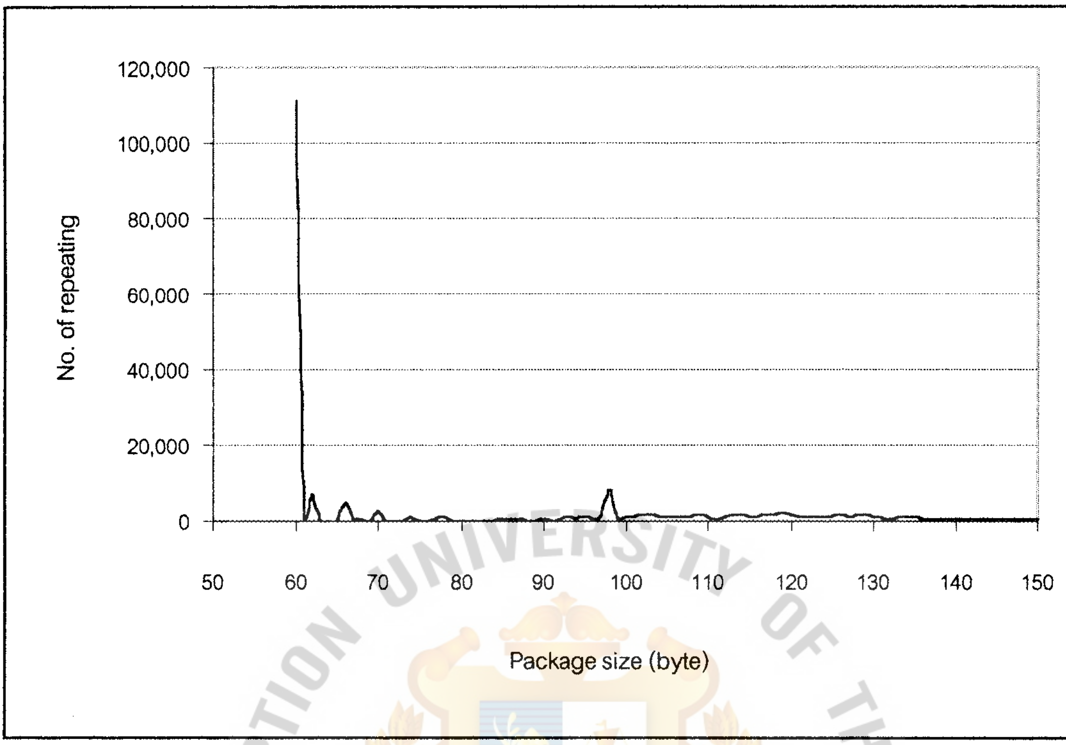


Figure 3.20 The graph of packet size on Tuesday.

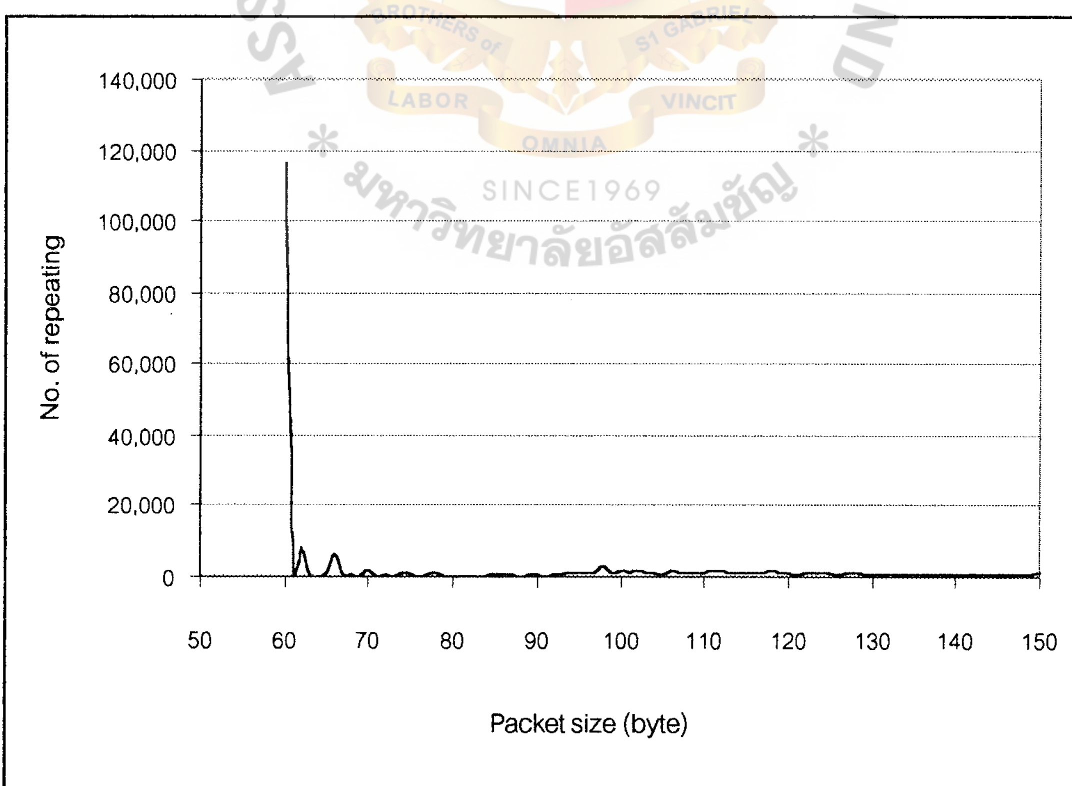


Figure 3.21 The graph of packet size on Wednesday.

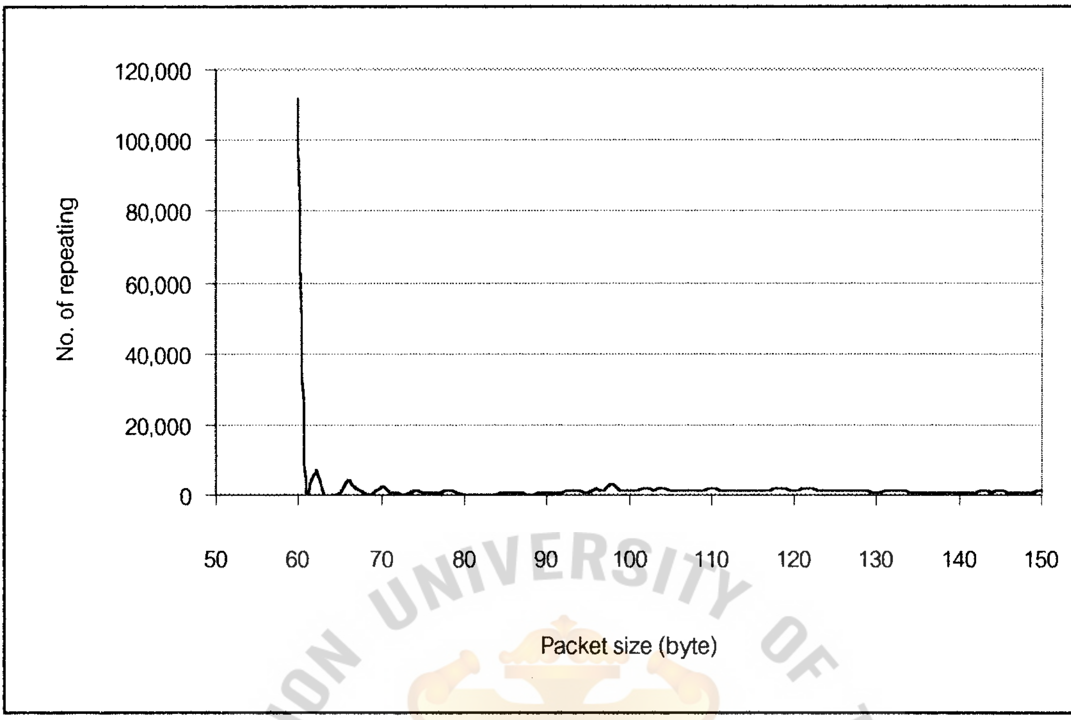


Figure 3.22 The graph of packet size on Thursday

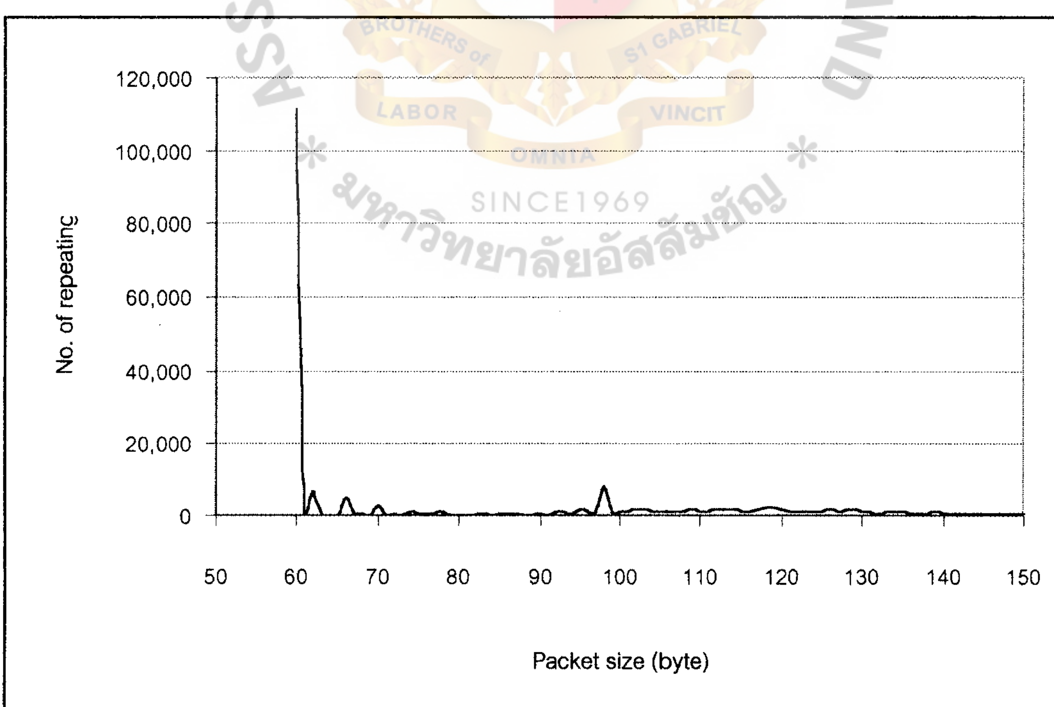


Figure 3.23 The graph of packet size on Friday.

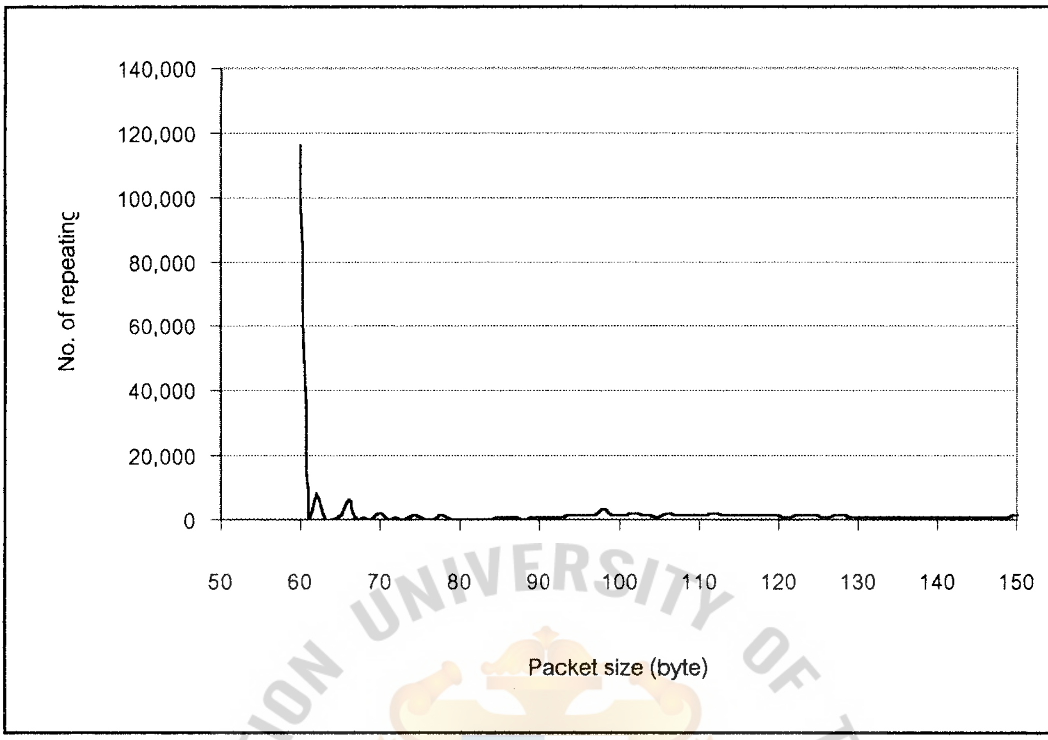


Figure 3.24 The graph of packet size on Saturday.

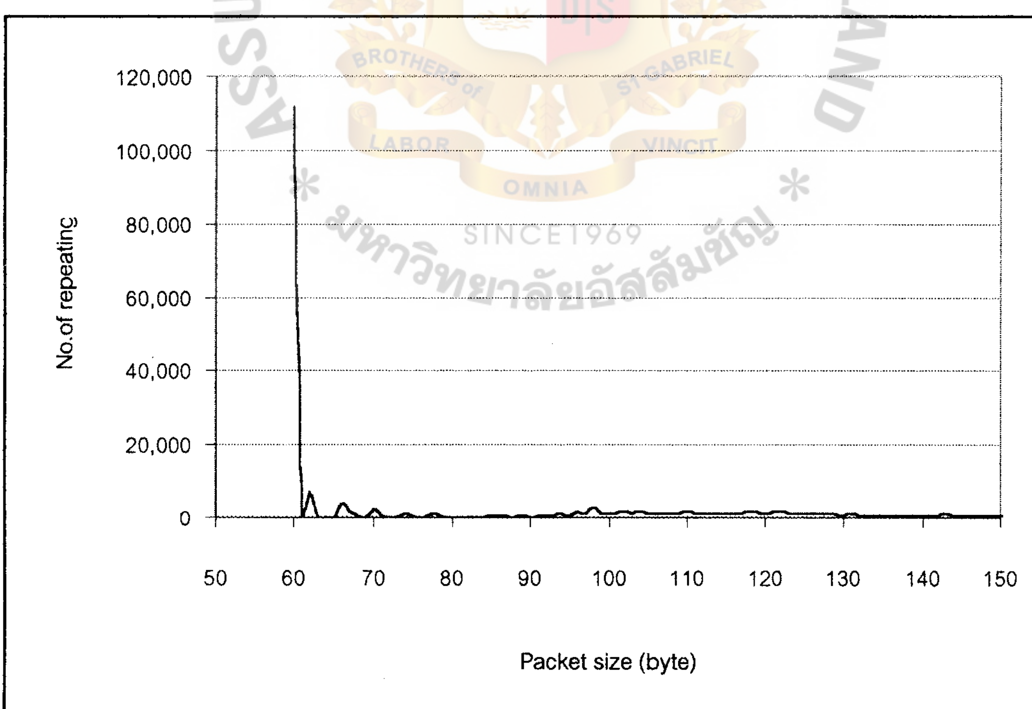


Figure 3.25 The graph of packet size on Sunday.

From the graph of interarrival time you will see its characteristic which is the number of interarrival time are maximum at 0.00006 and 0.00007 sec after that its will decrease until constant. So the arrival statistic may be exponential or deterministic distribution.

From the graph of packet size you will see that the number of the packet size equal to 60 byte is more than the other packet size very much which can say that the packet size from ABAC network is constant at 60 byte. So the arrival statistic should be deterministic distribution.

CHAPTER 4. CALCULATION

This chapter presents the calculation results by using the data measured as in Chapter3. Queuing theory is used to calculate the value of total waiting time in queue (T) and expect number of packets in queue (N). The calculation results are to be compared with the simulation results using measurement data in Chapter 5 and complete simulation results using Opnet module in Chapter 6.

4.1 M/D/1 System

It is assume that the arriving process is Poisson. The Poisson process has characteristic of independent and exponential distributed interarrival times. The Probability Density Function (pdf) of the interarrival times is given by

$$P(\tau n) = \lambda e^{-\lambda \tau_n}$$

Where

λ = Arrival rate

τn = Interarrival time for n=1,2,...

And since we are assumed to be the packet sizes almost constant at 480 bit. So the service times can be assumed deterministic. There is one link connected to the Internet from AUNet and Queuing system is M/D/1. It is assumed that the random variables (X_1,X_2,...) are identically distributed, mutually independent, and independent of the interarrival times.

Let

$$\overline{X} = E\{X\} = 1/\mu = \text{Average service time}$$

$$\overline{X^2} = E\{X^2\} = \text{Second moment of service time}$$

for the M/D/1 system

$$\overline{X^2} = 1/\mu^2$$

from the Pollaczek-Khinchin(P-K) formula for M/G/1:

$$W = \frac{\lambda \overline{X^2}}{2(1-\rho)}$$

where

W is the expect customer waiting time in queue

ρ is the utilization equal to λ / μ or $\lambda \overline{X}$

So the total waiting time, in the queue and in service, for M/D/1 is

$$T = \overline{X} + \frac{\lambda \overline{X^2}}{2(1-\rho)}$$

Applying Little's formula to W and T, we get the expected number of customers in the queue N_Q and the expected number in the system N are then:

$$N_Q = \lambda W = \frac{\lambda^2 \overline{X^2}}{2(1-\rho)}$$

and

$$N = \lambda T = \rho + \frac{\lambda^2 \overline{X^2}}{2(1-\rho)}$$

The link capacity is 10 Mb/s, therefore

The service rate	=	$10^6 / 480$	=	20.833	Kframe/sec
The X	=	$1/\mu$	=	4.8×10^{-5}	sec
The $\overline{X^2}$	=	$1/\mu^2$	=	2.304×10^{-9}	sec

Table 4.1 The calculation result of T and N on Monday by using M/D/1 queuing theory

Monday	The arriving rate (λ) (frame/sec)	The total waiting time in the queue (T) (sec)	The total number of frames in the queue(N) (frames)
8:00 a.m.	6815	5.970×10^{-5}	0.4066
9:00 a.m.	7185	6.063×10^{-5}	0.4356
10:00 a.m.	7218	6.072×10^{-5}	0.4383
11:00 a.m.	6874	5.982×10^{-5}	0.4112
12:00 a.m.	6743	5.984×10^{-5}	0.4011
1:00 p.m.	6869	5.980×10^{-5}	0.4108
2:00 p.m.	6705	5.939×10^{-5}	0.3982
3:00 p.m.	6465	5.880×10^{-5}	0.3801
4:00 p.m.	6039	5.770×10^{-5}	0.3490
5:00 p.m.	7246	6.079×10^{-5}	0.4405

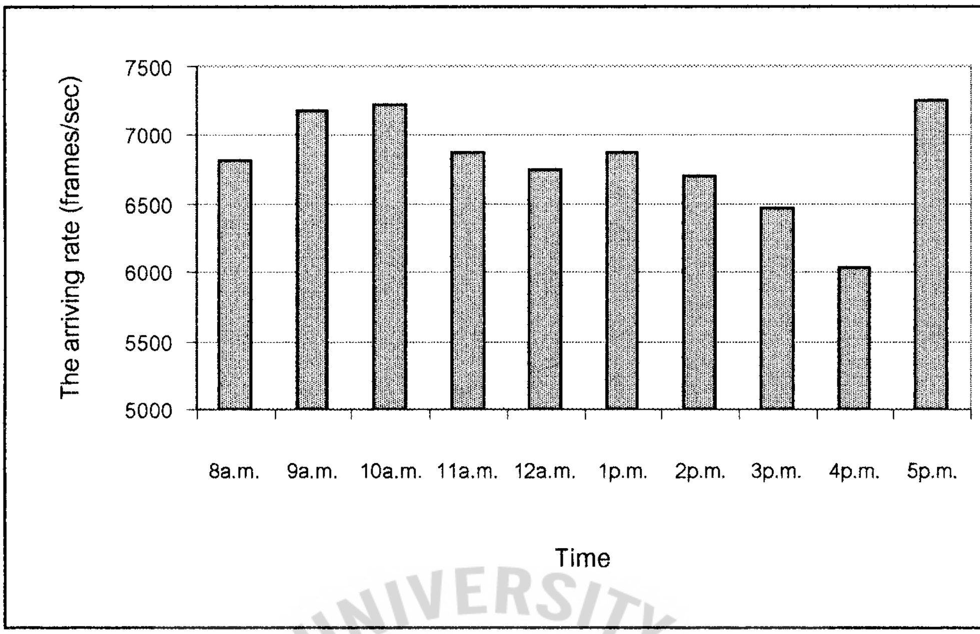


Figure 4.1 The Graph of arriving rate on Monday

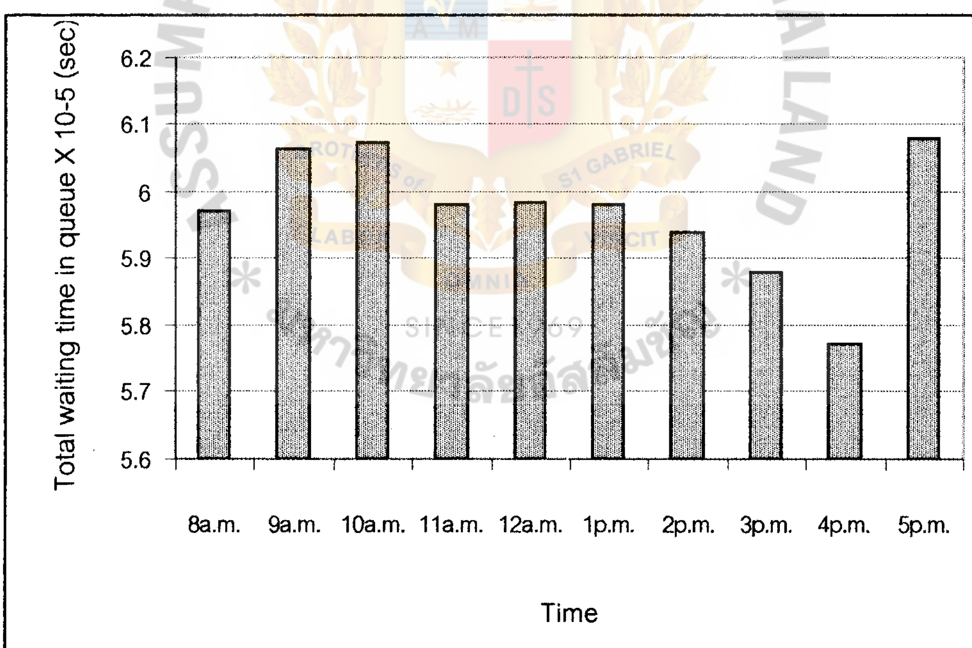


Figure 4.2 The Graph of total waiting time in the queue (T) on Monday

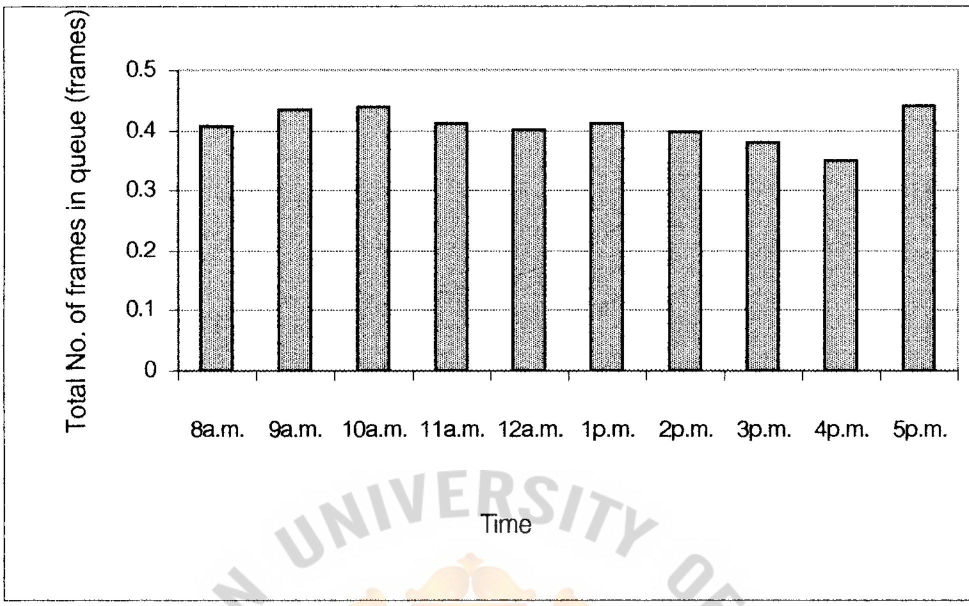


Figure 4.3 The graph of total number of packet in queue on Monday

Table 4.2 The calculation result of T and N in one week by using M/D/1 queuing theory

	Arriving rate (λ) (frame/sec)	Total waiting time in queue T (sec)	Total number of frames in queue (frames)
Monday	6815	5.97 x 10-5	0.4066
Tuesday	7130	6.0487 x 10-5	0.4313
Wednesday	7003	6.0152 x 10-5	0.4212
Thursday	6857	5.9775 x 10-5	0.4099
Friday	7073	6.0336 x 10-5	0.4268
Saturday	7014	6.0181 x 10-5	0.4221
Sunday	6835	5.9718 x 10-5	0.4081

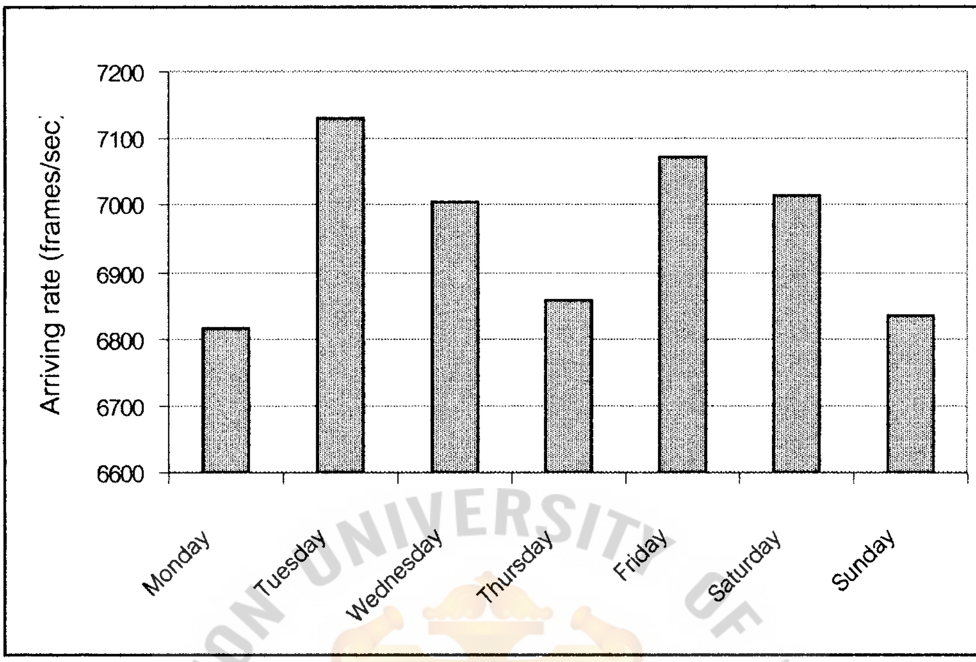


Figure 4.4 The graph of arriving rate in one week

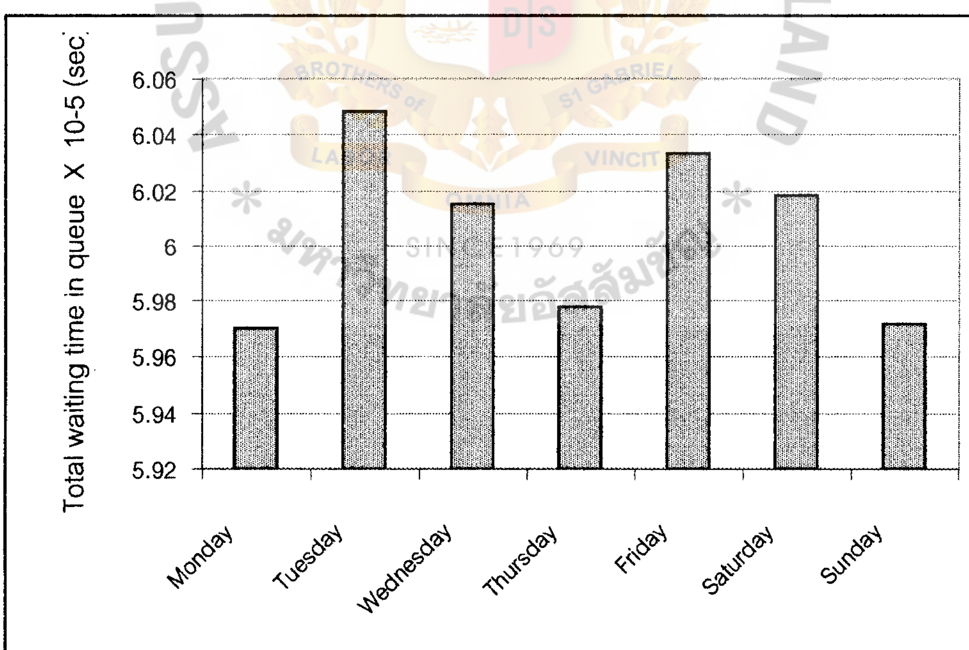


Figure 4.5 The graph of total waiting time in queue in one week

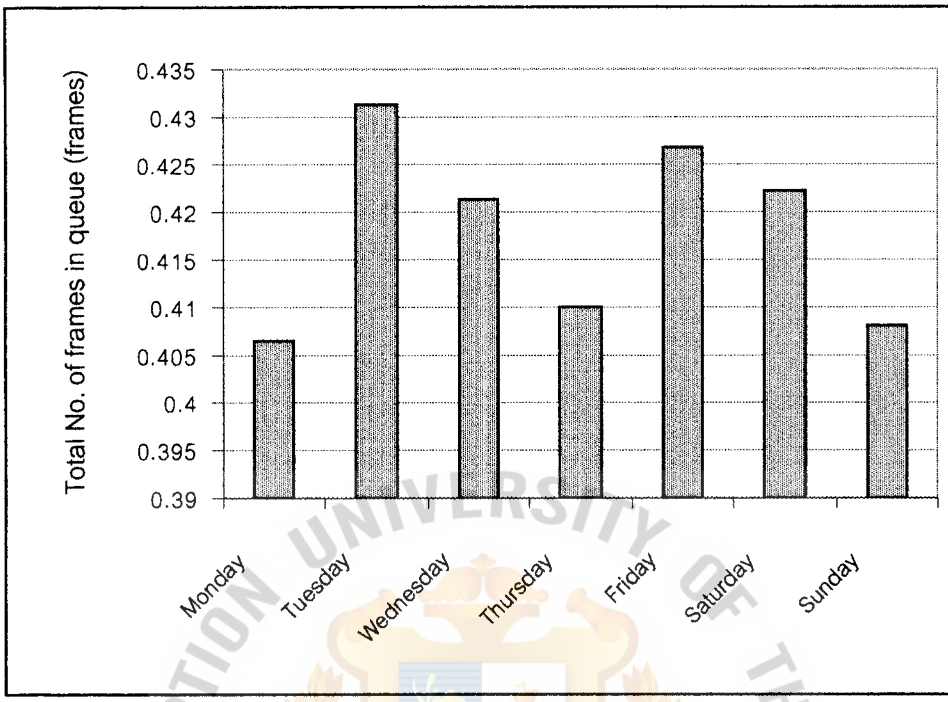


Figure 4.6 The graph of total number of frames in queue

When change the service rate to be 100 Mb/s so

The service rate = $10^8 / 480$ = 208.33 Kframe/sec

The $\overline{X}$ = $1/\mu$ = 4.8×10^{-6} sec

The $\overline{X^2}$ = $1/\mu^2$ = 2.304×10^{-11} sec

Table 4.3 The calculation result of T and N when changing service rate to 100 Mb/s

	The total time waiting in the queue (T) (sec)	The total number of packet in the queue (N) (frame)
Monday	4.881×10^{-6}	0.03326
Tuesday	4.885×10^{-6}	0.03483
Wednesday	4.883×10^{-6}	0.03420
Thursday	4.881×10^{-6}	0.03347
Friday	4.884×10^{-6}	0.03454
Saturday	4.883×10^{-6}	0.03425
Sunday	4.881×10^{-6}	0.03336

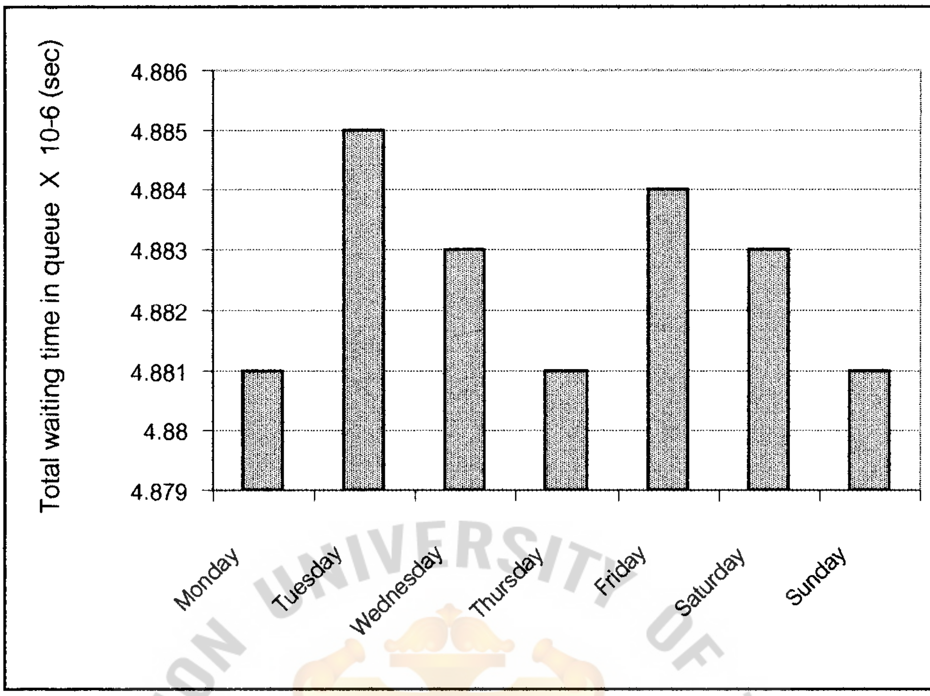


Figure 4.7 The graph of total waiting time in queue when service rate is 100 Mb/s

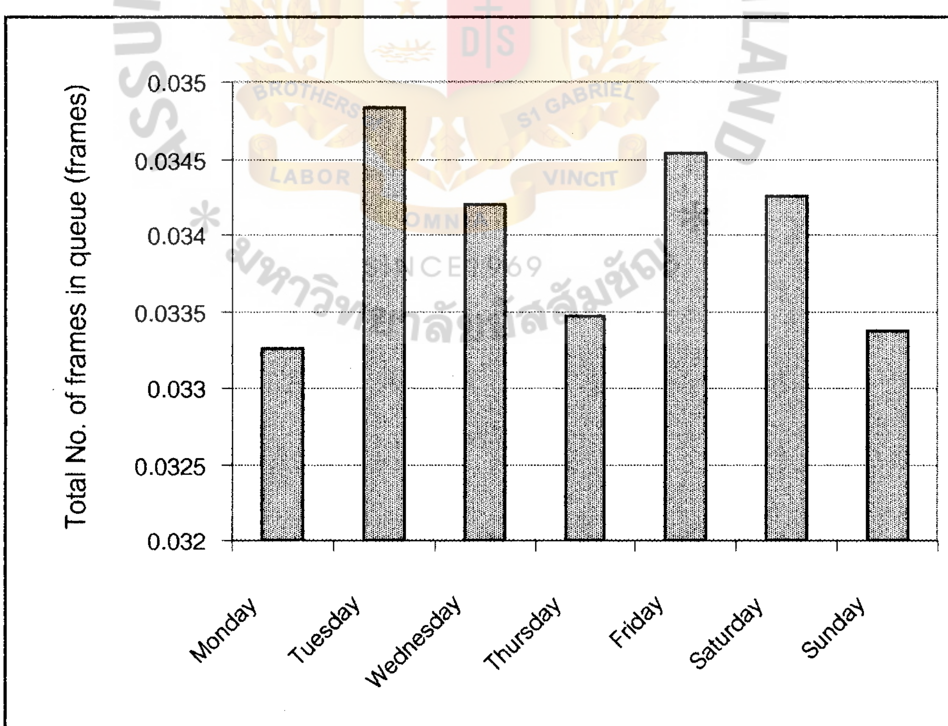


Figure 4.8 The graph of total number of packet in queue when service rate is 100 Mb/s

I will use other Queuing system (D/D/1 and G/D/1) to analyze the Internet traffic in Assumption University. The D/D/1 and G/D/1 Queuing system can use the G/G/1 Queuing system to analyze. The formula of waiting time in the Queue for G/G/1 Queuing system is

$$W \leq \frac{\lambda(\sigma^2_a + \sigma^2_b)}{2(1-\rho)} - \frac{\lambda(1-\rho)\sigma^2_a}{2}$$

Where

σ_a^2 = Variance of the interarrival times

σ_b^2 = Variance of the service time

λ = Average interarrival time

ρ = Utilization factor λ / μ, where $1/\mu$ is the average service time

So

The total delay (T) = Processing time + Waiting time in the Queue

= $1/\mu + W$

and then use the Little's Theorem

Total Number of packet in the Queue (N) = λT

4.2 D/D/1 System

When using the D/D/1 queuing system by using the constant interarrival time at 0.00006461 sec this constant come from I weight the most frequency use of interarrival time of the Internet Protocol from Assumption University.

So

σ_a = 0

σ_b = 0

μ = 20,833 Frame/sec

λ = 1/0.00006461 = 1548 Frame/sec

So

$T \leq 4.8 \times 10^{-5}$ Sec

$N \leq 0.0743$ Frame

4.3 G/D/1 System

When using G/D/1 queuing system

$\sigma_b = 0$

$\mu = 20{,}833$ Frame/sec

$\lambda = 6{,}815$ Frame/sec

Table 4.4 The calculation result of n and T when using G/D/1 queuing system

	Variance of the interarrival times (σ_a^2)	Total waiting time in queue T (sec)	Total number of packet in queue N (frame)
Monday	5.2548×10^{-6}	$T \leq 4.80765 \times 10^{-5}$	$N \leq 0.3576$
Tuesday	4.9629×10^{-6}	$T \leq 4.80757 \times 10^{-5}$	$N \leq 0.3428$
Wednesday	4.9828×10^{-6}	$T \leq 4.80732 \times 10^{-5}$	$N \leq 0.3365$
Thursday	5.6951×10^{-6}	$T \leq 4.80908 \times 10^{-5}$	$N \leq 0.3297$
Friday	4.2034×10^{-6}	$T \leq 4.80532 \times 10^{-5}$	$N \leq 0.3399$
Saturday	5.6951×10^{-6}	$T \leq 4.80908 \times 10^{-5}$	$N \leq 0.3297$
Sunday	5.1186×10^{-6}	$T \leq 4.8073 \times 10^{-5}$	$N \leq 0.3286$

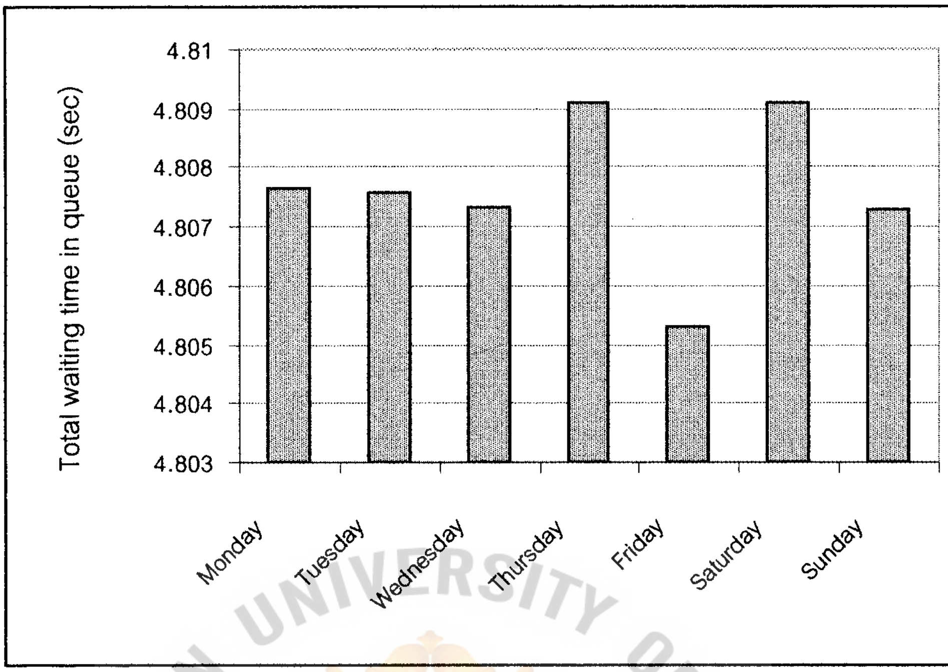


Figure 4.9 The graph of total delay in queue when using G/D/1 queuing system

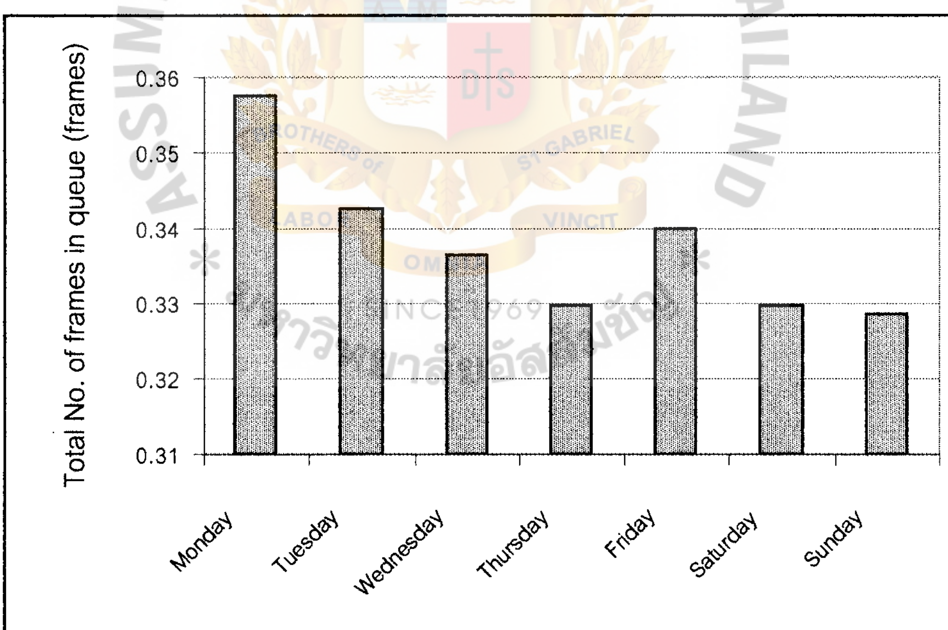


Figure 4.10 The graph of total number of packet in queue when using G/D/1 queuing system.

CHAPTER 5. SIMULATION BY USING MEASUREMENTS OF STATISTIC

This chapter presents the simulation results by using the measurement statistics of AuNet in Chapter 3. The results are presented as graph of queuing delay and queuing size. The measurement statistics will be applied to three queuing system : M/D/1, D/D/1 and G/D/1. Then each case will be compared with the calculation results achieved in Chapter 4. Then it will be decided which queuing is best suit for the ABAC Internet network. The method to simulate each queuing system can be found in the Tutorial of Opnet program [10].

Opnet program use to evaluate the queue size and queuing delay of the network. It can be done by using queuing system which depends on several parameters : packet arrival rate, packet size, and service capacity. To simulation each queuing system by First create the node model in the Node Editor which consist of modules connected by packet streams and statistic wires. Second step choose the results to view such as queue size and queuing delay in Probe Editor and last step is running the program and choose View Result menu the graph will show.

These are the result of model Assumption University by using the M/D/1 queuing theory

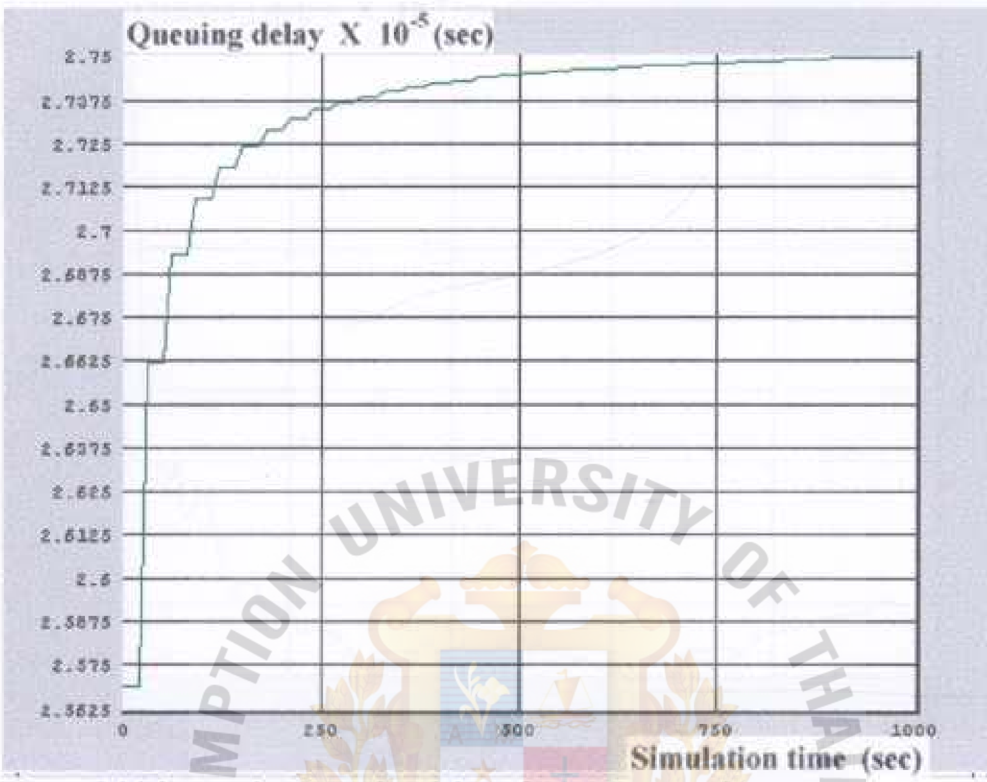


Figure 5.1 The graph of queuing delay of ABAC network

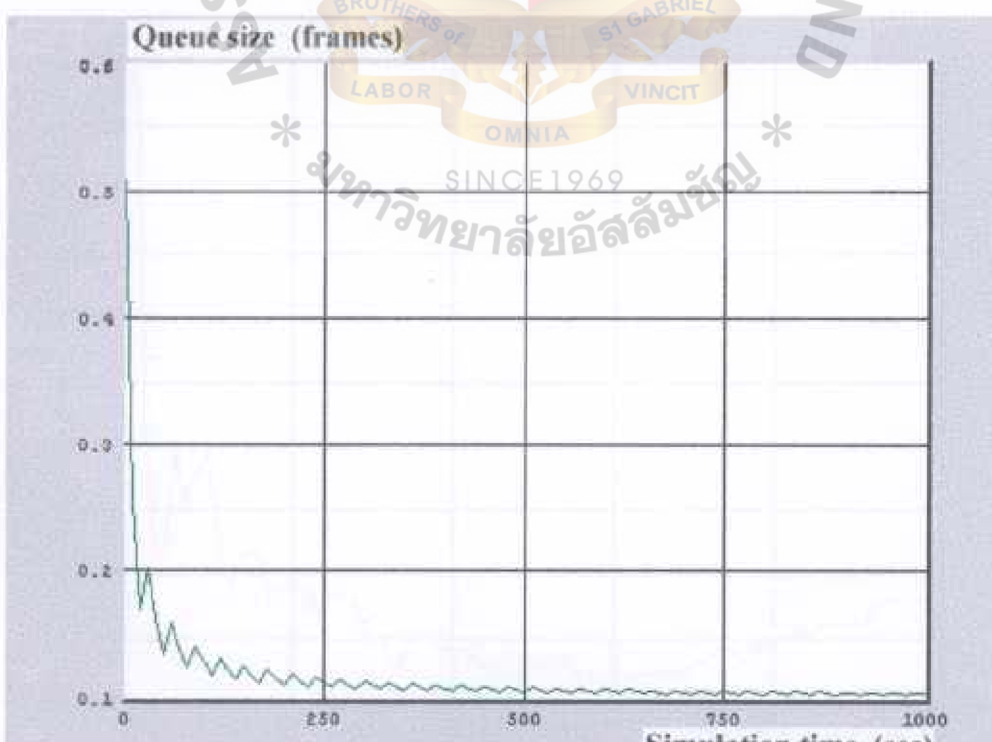


Figure 5.2 The graph of queue size of ABAC network

Monday at 8:00 a.m.

Figure 5.3 The graph of queuing delay on Monday at 8:00 a.m.

Figure 5.4 The graph of queue size on Monday at 8:00 a.m.

Monday at 9:00 a.m.

Figure 5.5 The graph of queuing delay on Monday at 9:00 a.m.

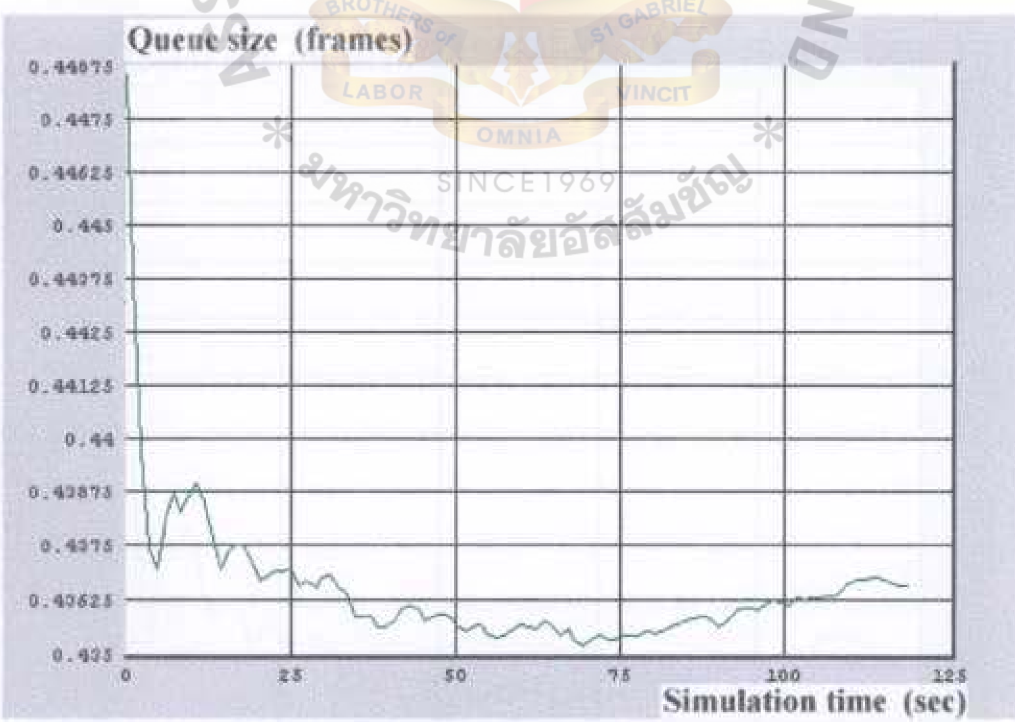


Figure 5.6 The graph of queue size on Monday at 9:00 a.m.

Monday at 10:00 a.m.

Figure 5.7 The graph of queuing delay on Monday at 10:00 a.m.

Figure 5.8 The graph of queue size on Monday at 10:00 a.m.

Monday at 11:00 a.m.

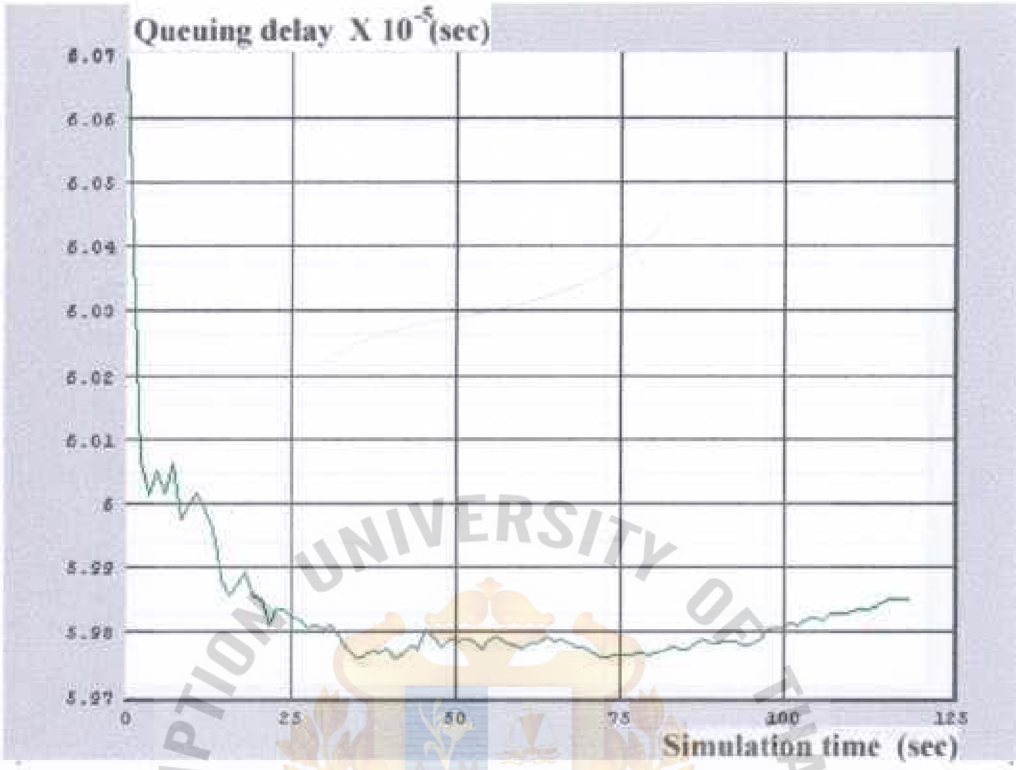


Figure 5.9 The graph of queuing delay on Monday at 11:00 a.m.

Figure 5.10 The graph of queue size on Monday at 11:00 a.m.

Monday at 12:00 a.m.

Figure 5.11 The graph of queuing delay on Monday at 12:00 a.m.

Figure 5.12 The graph of queue size on Monday at 12:00 a.m.

Monday at 1:00 p.m.

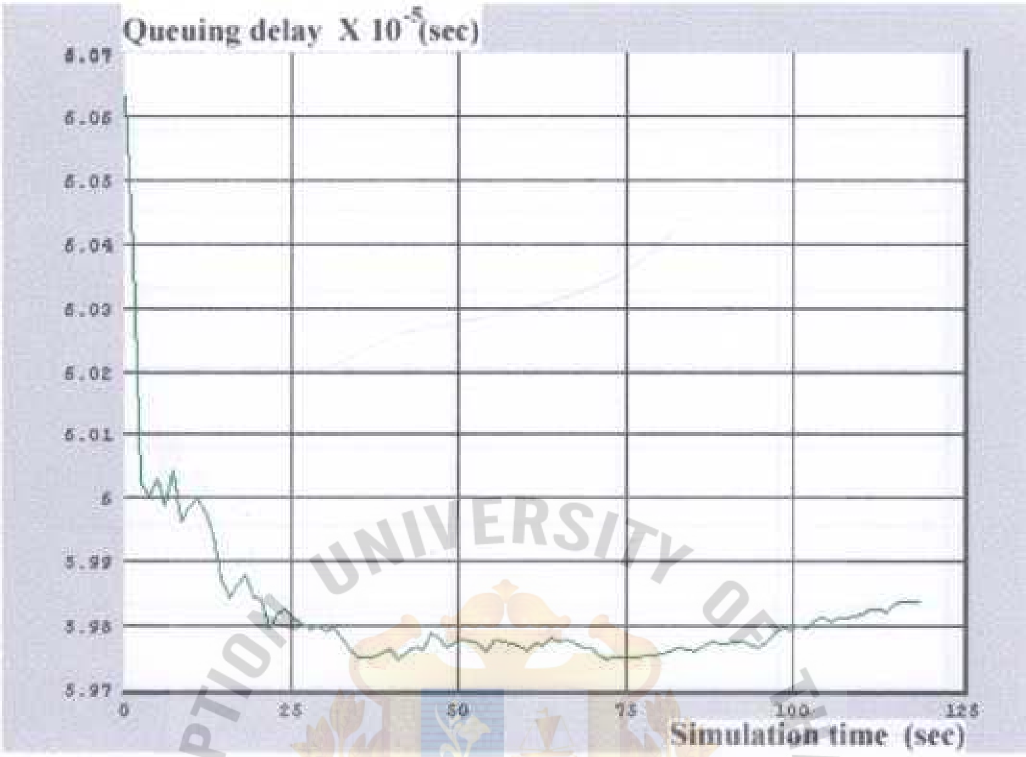


Figure 5.13 The graph of queuing delay on Monday at 1:00 p.m.

Figure 5.14 The graph of queue size on Monday at 1:00 p.m.

Monday at 2:00 p.m.

Figure 5.15 The graph of queuing delay on Monday at 2:00 p.m.

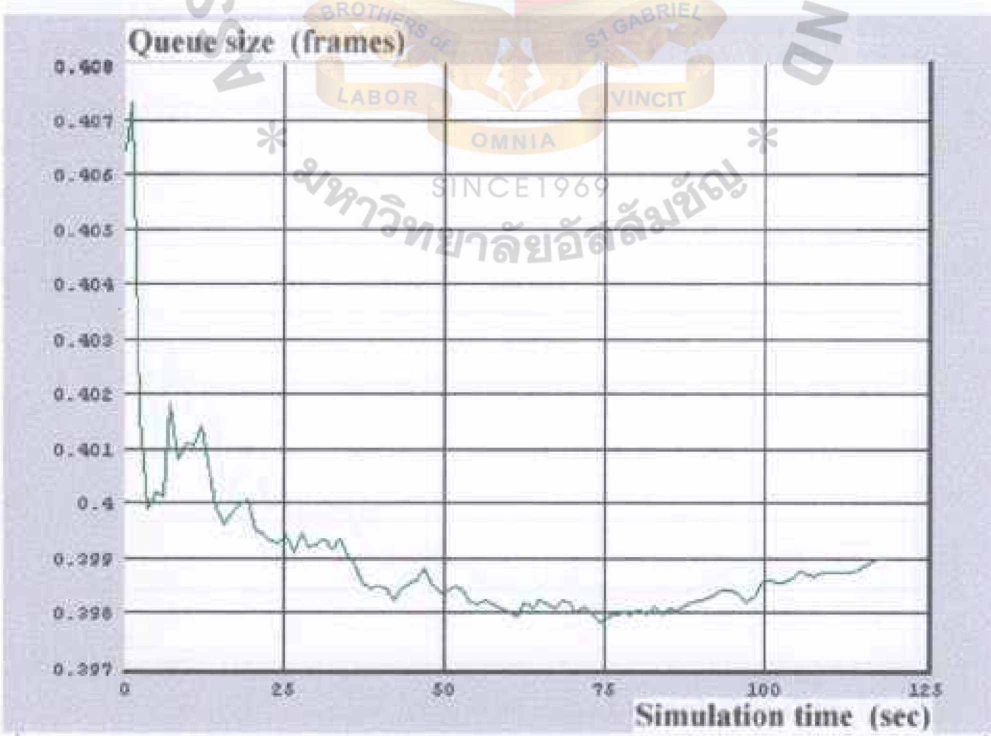


Figure 5.16 The graph of queue size on Monday at 2:00 p.m.

Monday at 3:00 p.m.

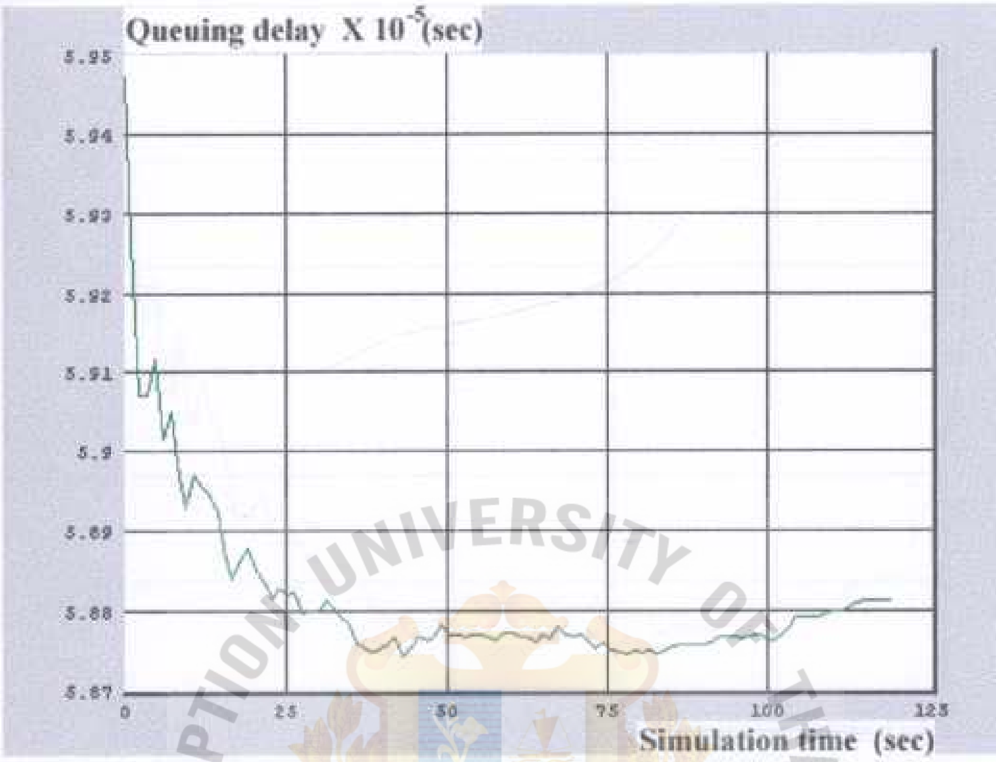


Figure 5.17 The graph of queuing delay on Monday at 3:00 p.m.

Figure 5.18 The graph of queue size on Monday at 3:00 p.m.

Monday at 4:00 p.m.

Figure 5.19 The graph of queuing delay on Monday at 4:00 p.m.

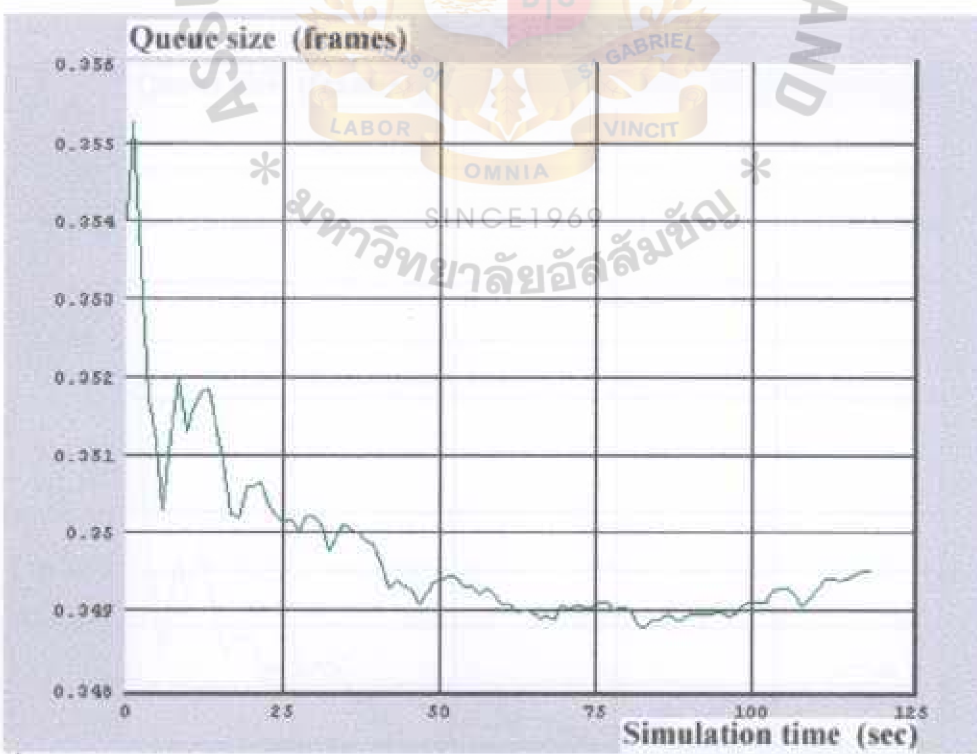


Figure 5.20 The graph of queue size on Monday at 4:00 p.m.

Monday at 5:00 p.m.

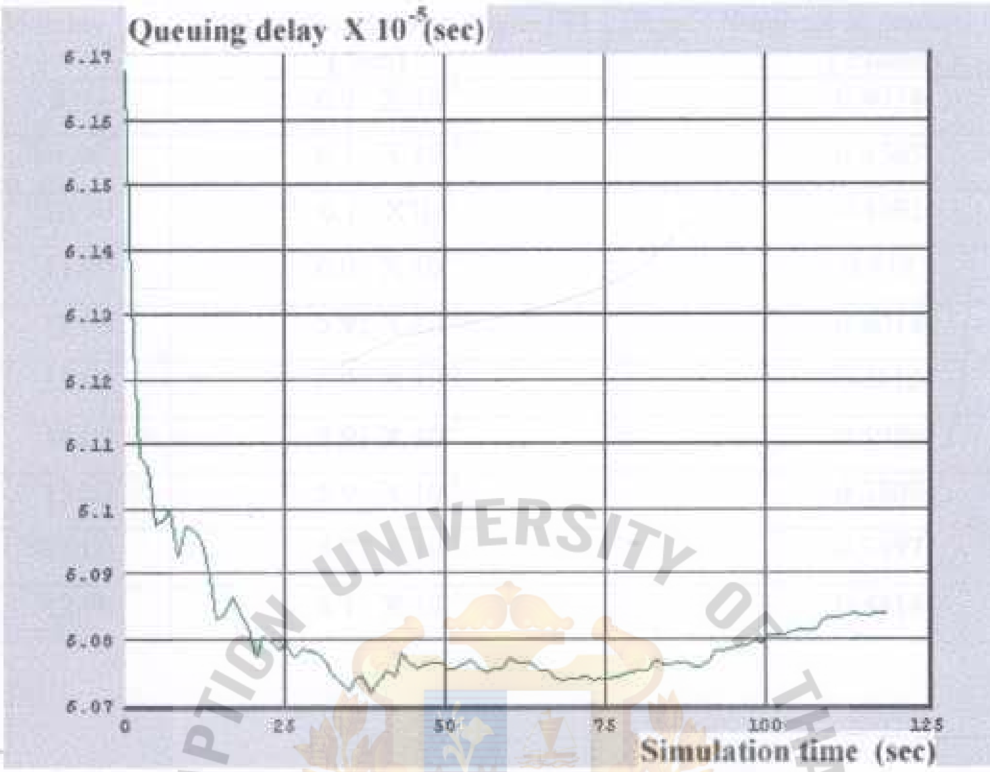


Figure 5.21 The graph of queuing delay on Monday at 5:00 p.m.

Figure 5.22 The graph of queue size on Monday at 5:00 p.m.

Table 5.1 The results of T and N on Monday by using M/D/1 at steady state

Monday	Total waiting time in queue (T) (Sec)	Expect Numbers of packets in queue(N) (Frames)
8:00	6.0×10^{-5}	0.4074
9:00	6.1×10^{-5}	0.4365
10:00	6.1×10^{-5}	0.4391
11:00	6.0×10^{-5}	0.412
12:00	5.92×10^{-5}	0.4018
13:00	6.0×10^{-5}	0.4116
14:00	5.91×10^{-5}	0.3989
15:00	5.9×10^{-5}	0.3809
16:00	5.77×10^{-5}	0.3497
17:00	6.1×10^{-5}	0.4414

Monday

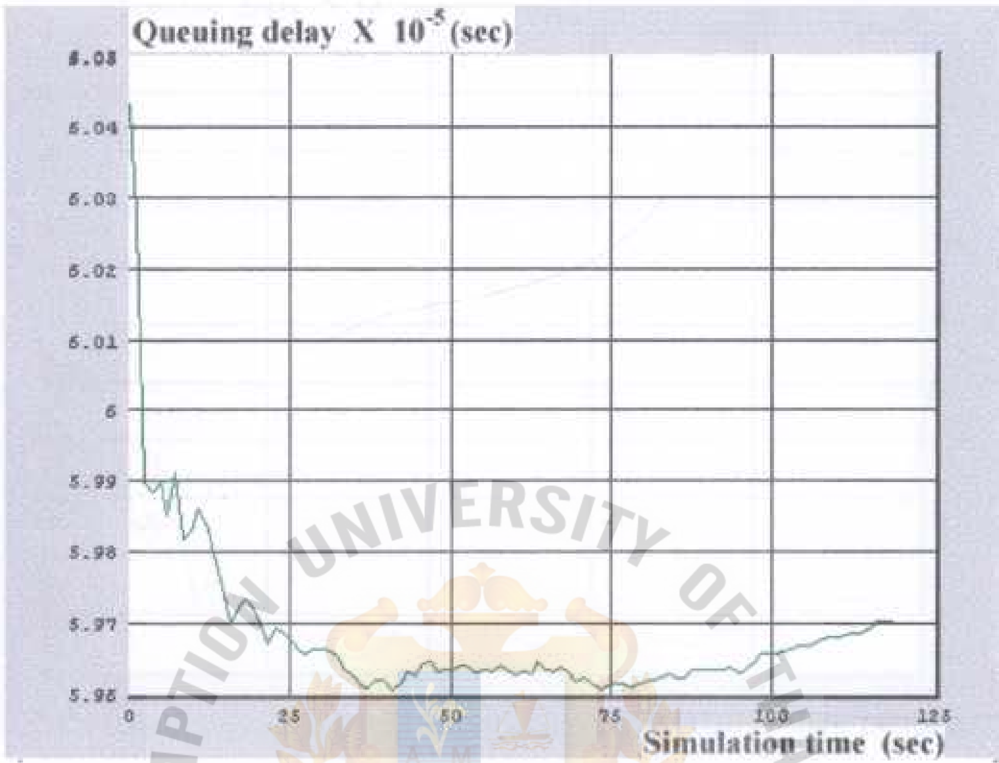


Figure 5.23 The graph of queuing delay on Monday

Figure 5.24 The graph of queue size on Monday

Tuesday

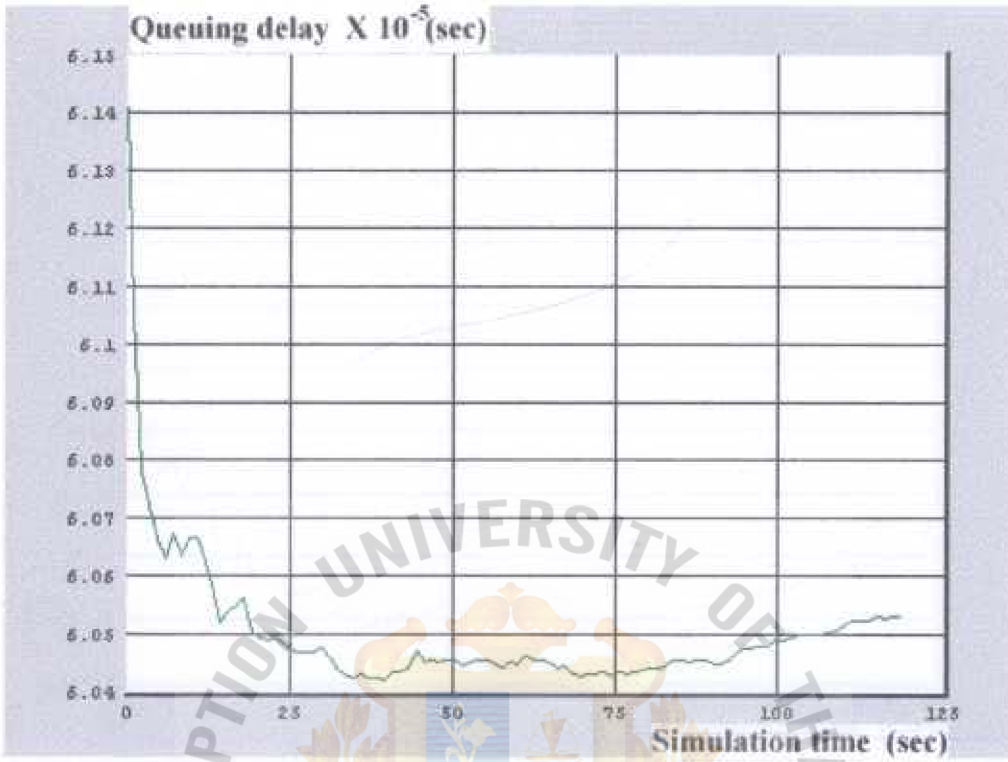


Figure 5.25 The graph of queuing delay on Tuesday

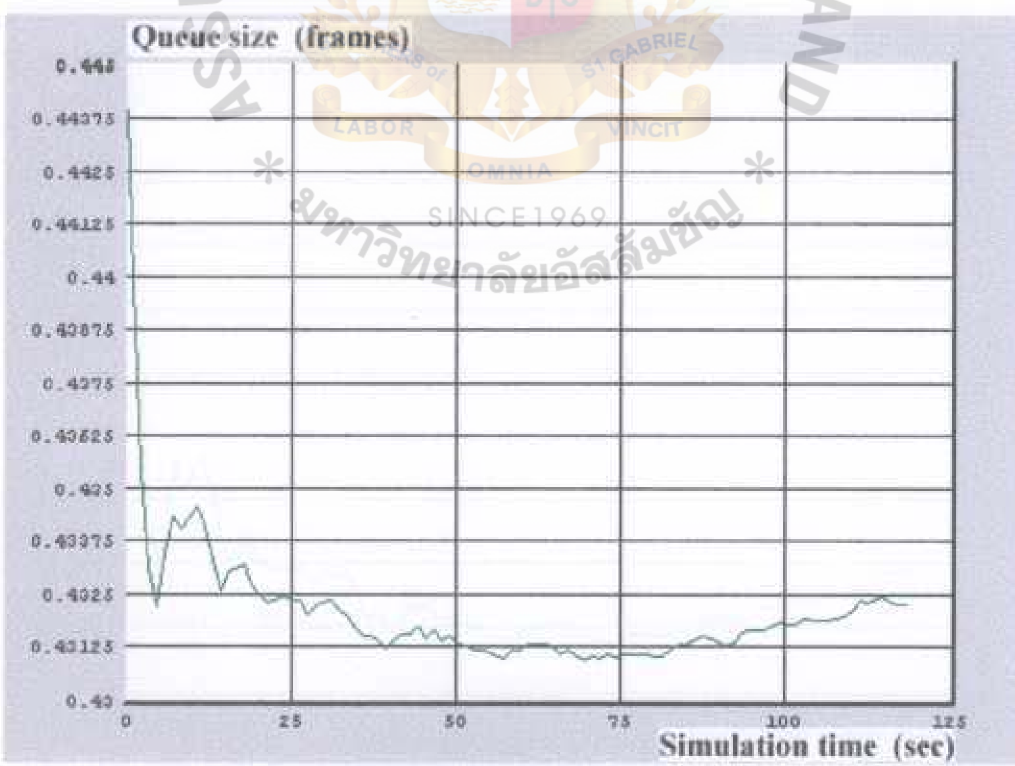


Figure 5.26 The graph of queue size on Tuesday

Wednesday

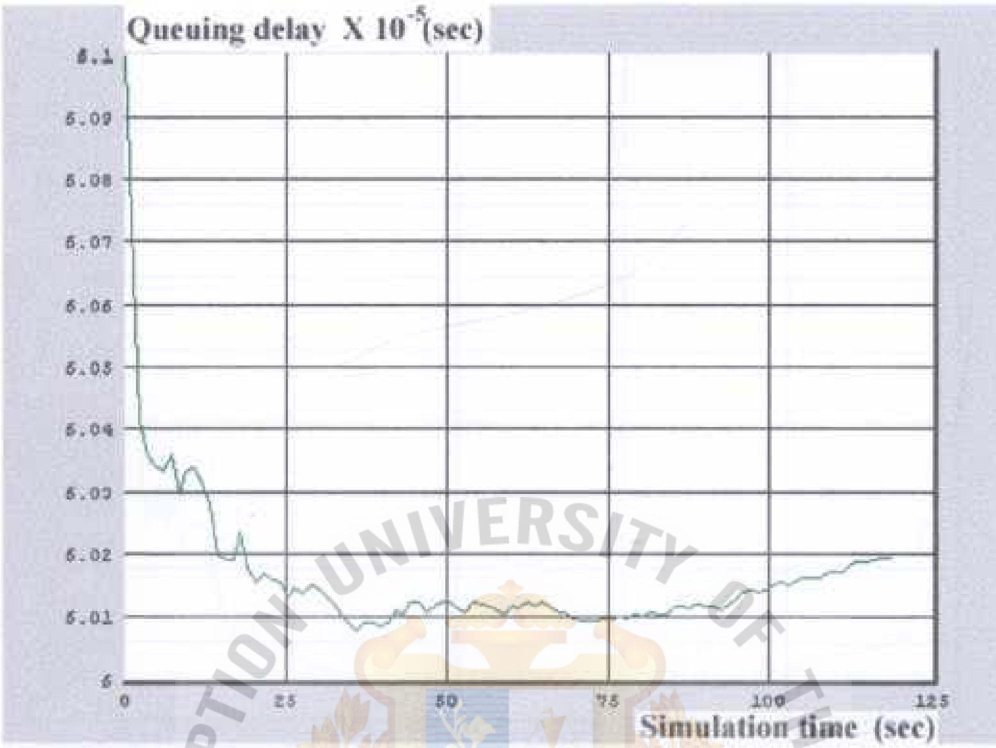


Figure 5.27 The graph of queuing delay on Wednesday

Figure 5.28 The graph of queue size on Wednesday

Thursday

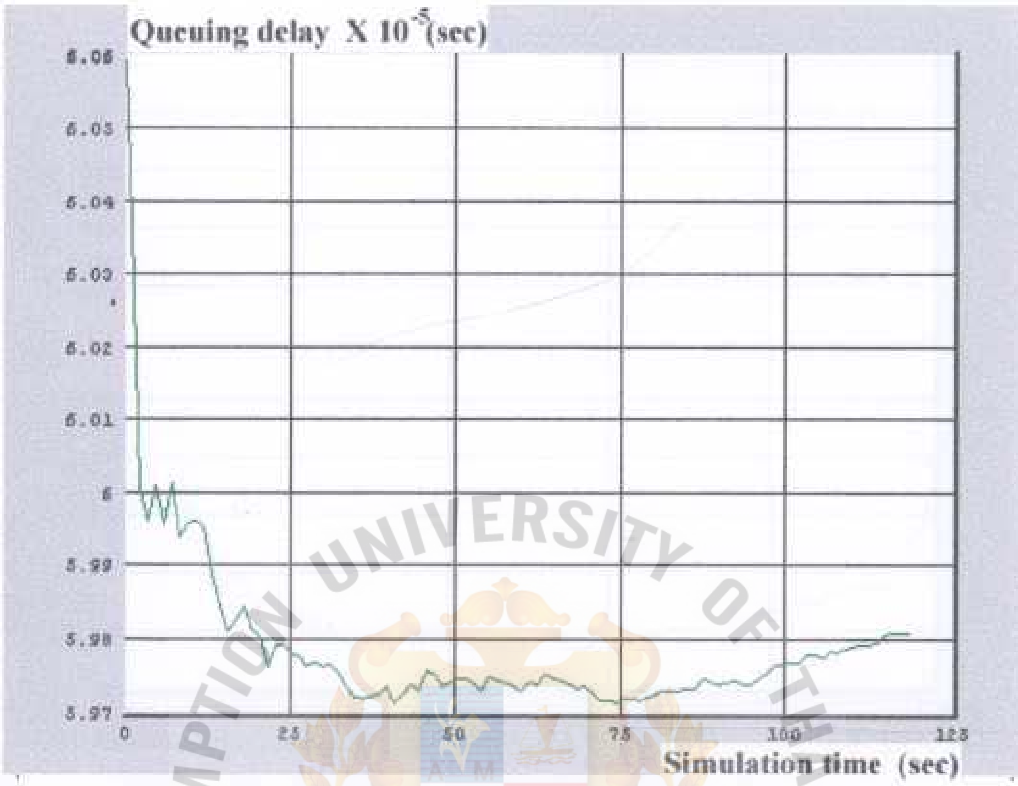


Figure 5.29 The graph of queuing delay on Thursday

Figure 5.30 The graph of queue size on Thursday

Friday

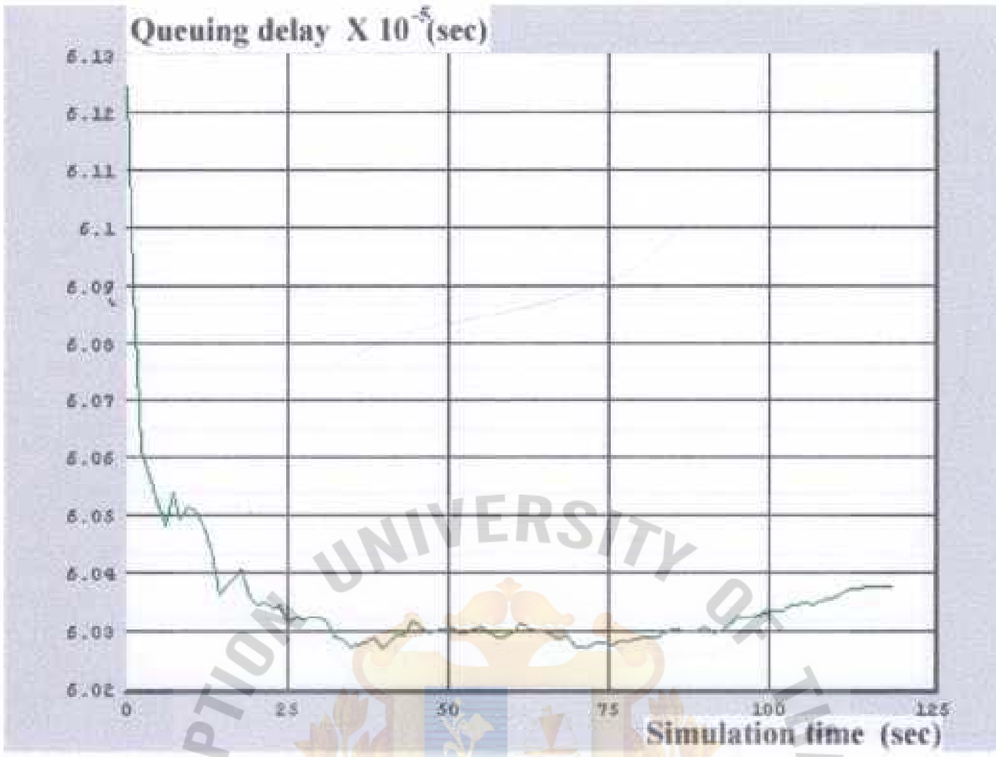


Figure 5.31 The graph of queuing delay on Friday

Figure 5.32 The graph of queue size on Friday

Saturday

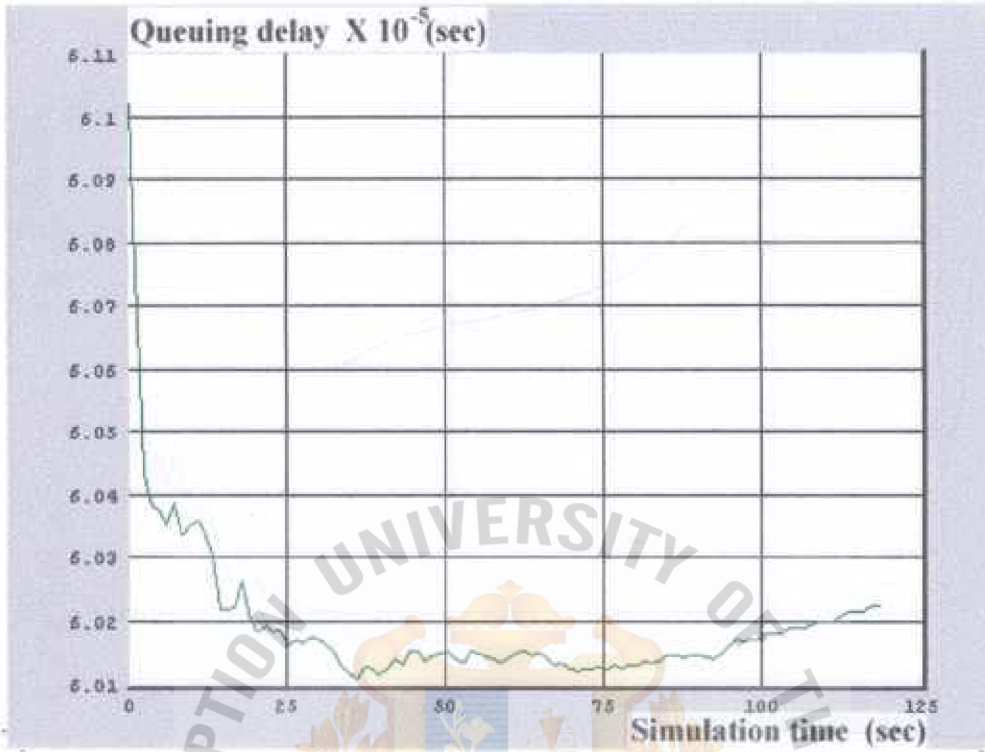


Figure 5.33 The graph of queuing delay on Saturday

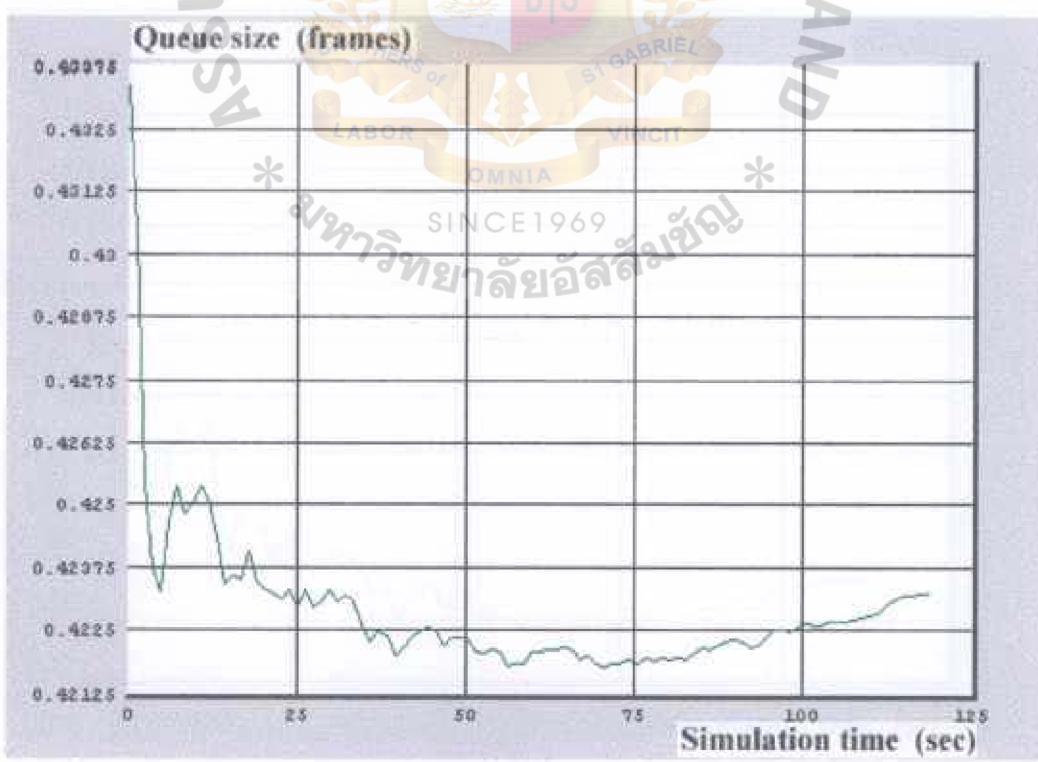


Figure 5.34 The graph of queue size on Saturday

Sunday

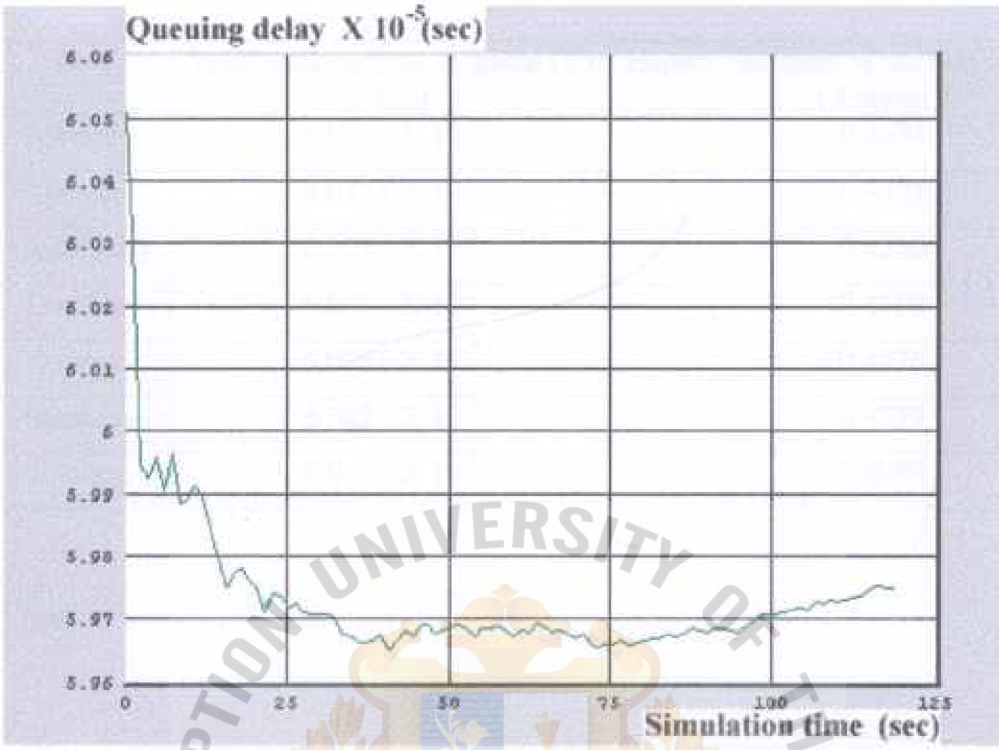


Figure 5.35 The graph of queuing delay on Sunday

Figure 5.26 The graph of queue size on Sunday

Table 5.2 The results of T and N in one week by using M/D/1 at steady state

Day	Total waiting time in queue (T) (Sec)	Expect Numbers of packets in queue(N) (Frames)
Monday	6.0 $\times 10^{-5}$	0.4074
Tuesday	6.0273 $\times 10^{-5}$	0.4321
Wednesday	6.002 $\times 10^{-5}$	0.4220
Thursday	6.0 $\times 10^{-5}$	0.4100
Friday	6.0081 $\times 10^{-5}$	0.4276
Saturday	6.002 $\times 10^{-5}$	0.4229
Sunday	6.0 $\times 10^{-5}$	0.4089

These are the result of model Assumption University by using the D/D/1 queuing theory

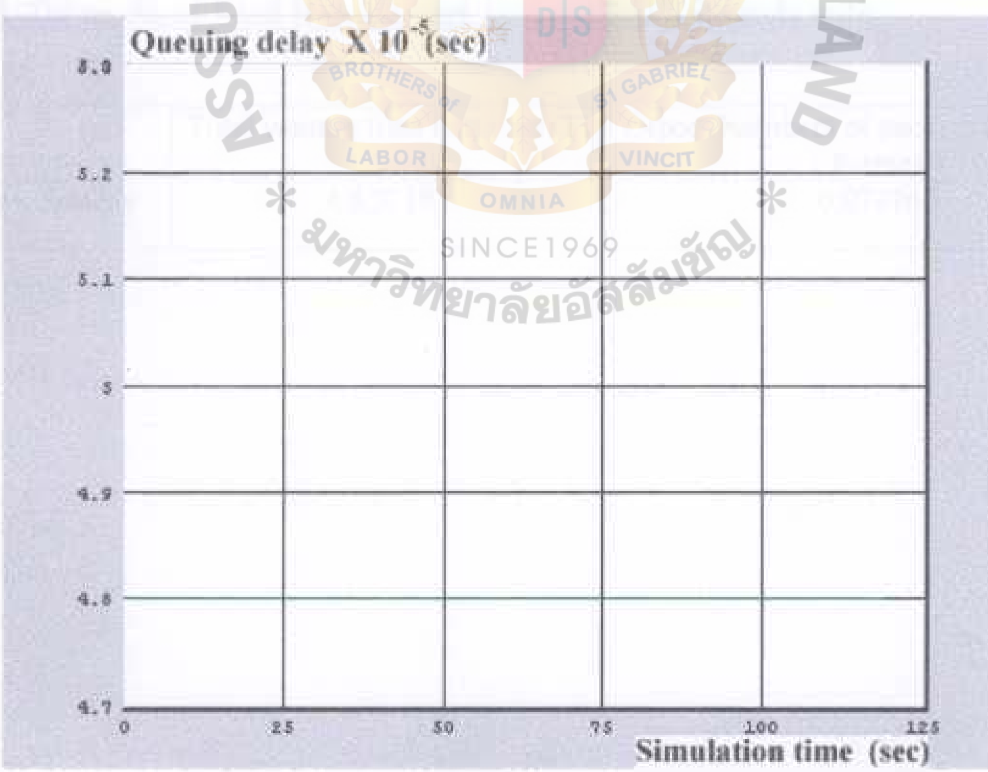


Figure 5.37 The graph of queuing delay by using D/D/1 queuing theory

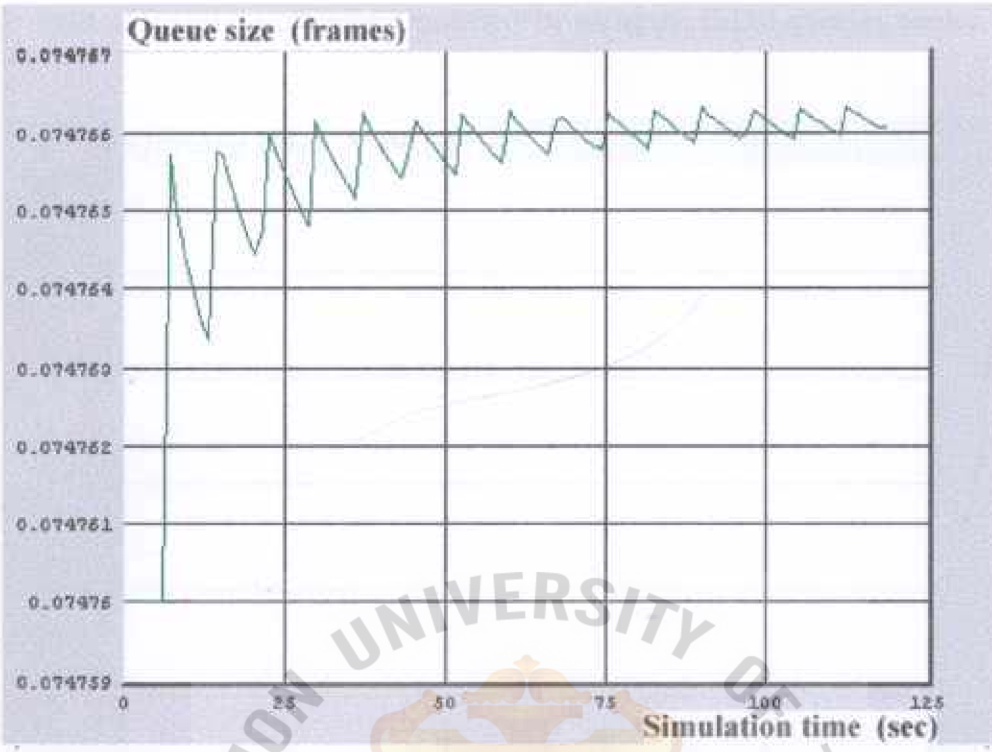


Figure 5.38 The graph of queue size by using D/D/1 queuing theory

Table 5.3 The results of T and N in one week by using D/D/1 at steady state

Day	Total waiting time in queue (T) (Sec)	Expect Numbers of packets in queue(N) (Frames)
Monday - Sunday	4.8×10^{-5}	0.074766

These are the result of model Assumption University by using the G/D/1 queuing theory.
On Monday

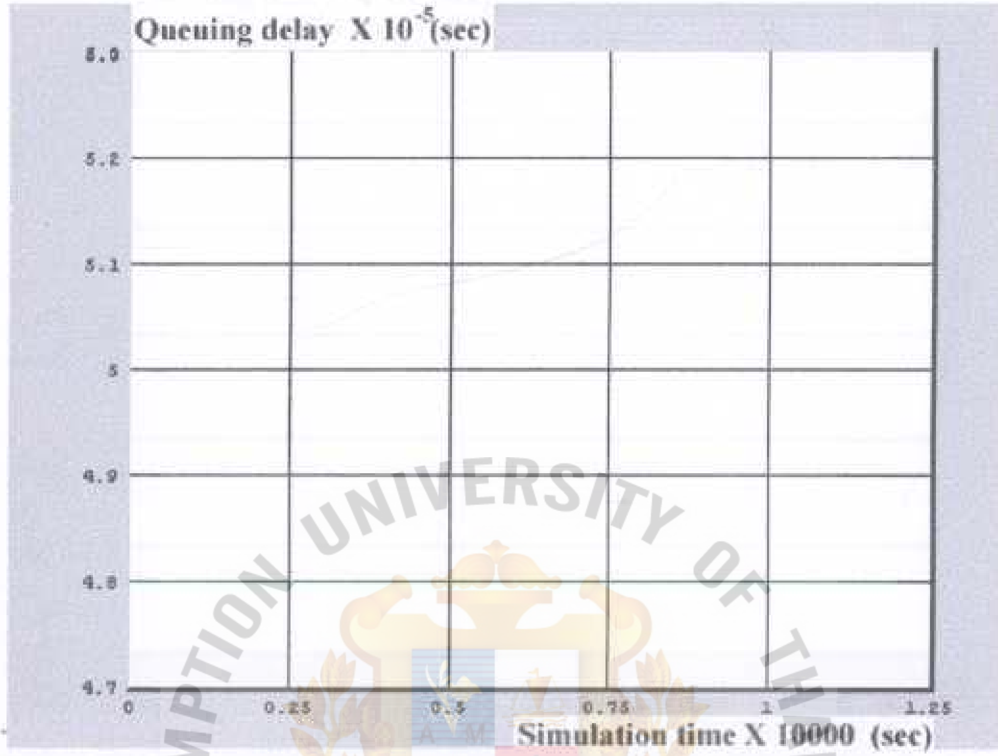


Figure 5.39 The graph of queuing delay on Monday by using G/D/1 queuing theory

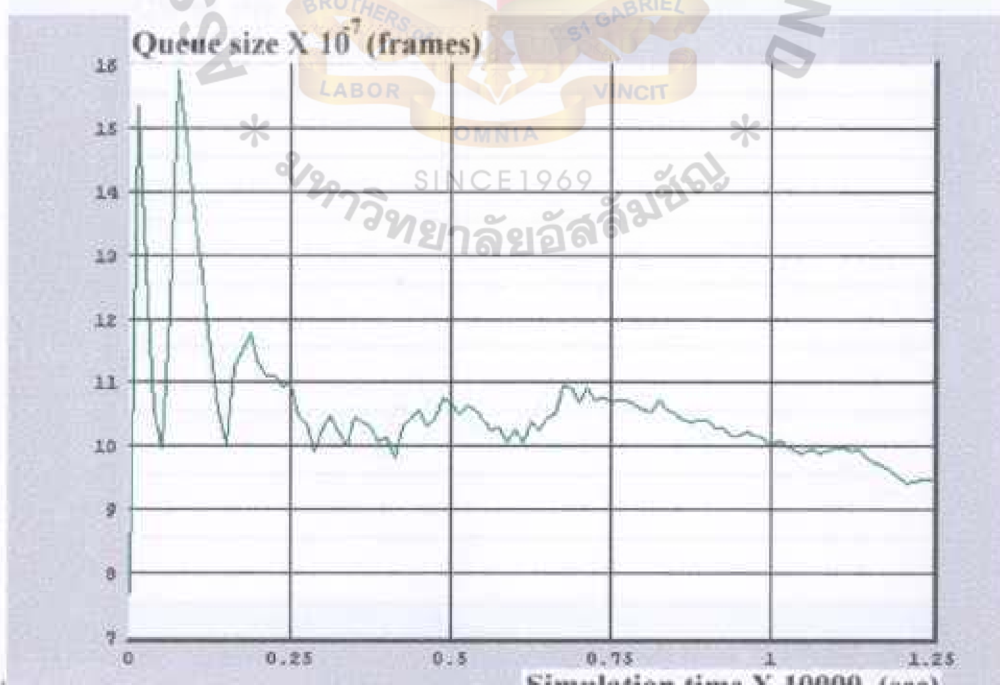


Figure 5.40 The graph of queue size on Monday by using G/D/1 queuing theory

Tuesday

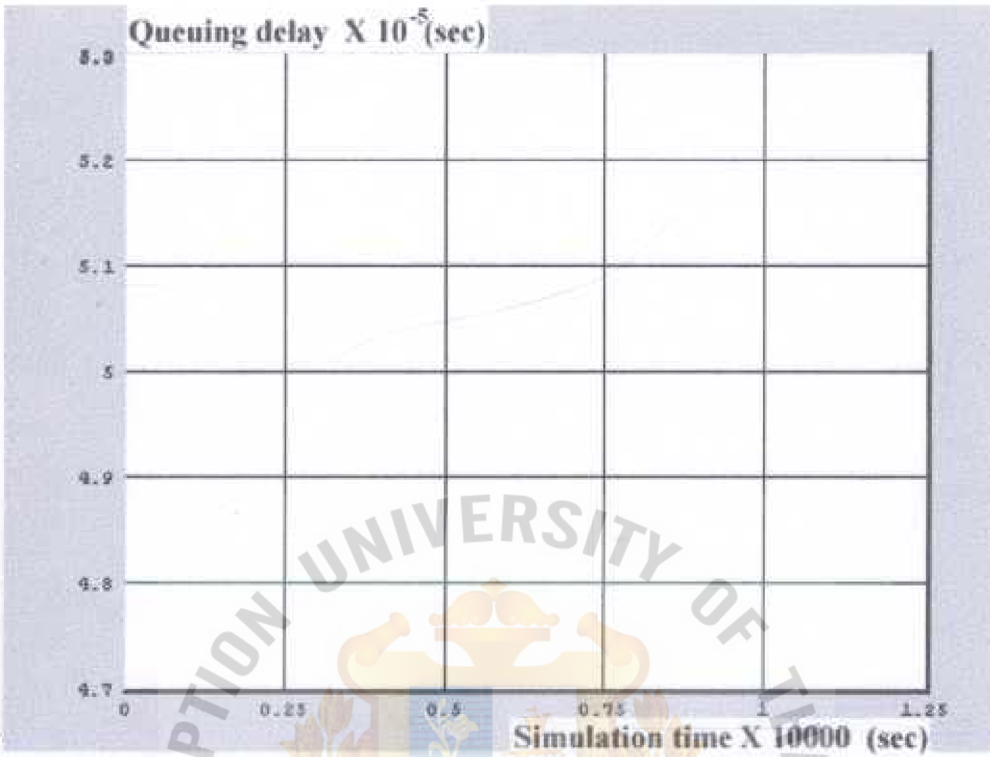


Figure 5.41 The graph of queuing delay on Tuesday by using G/D/1 queuing theory

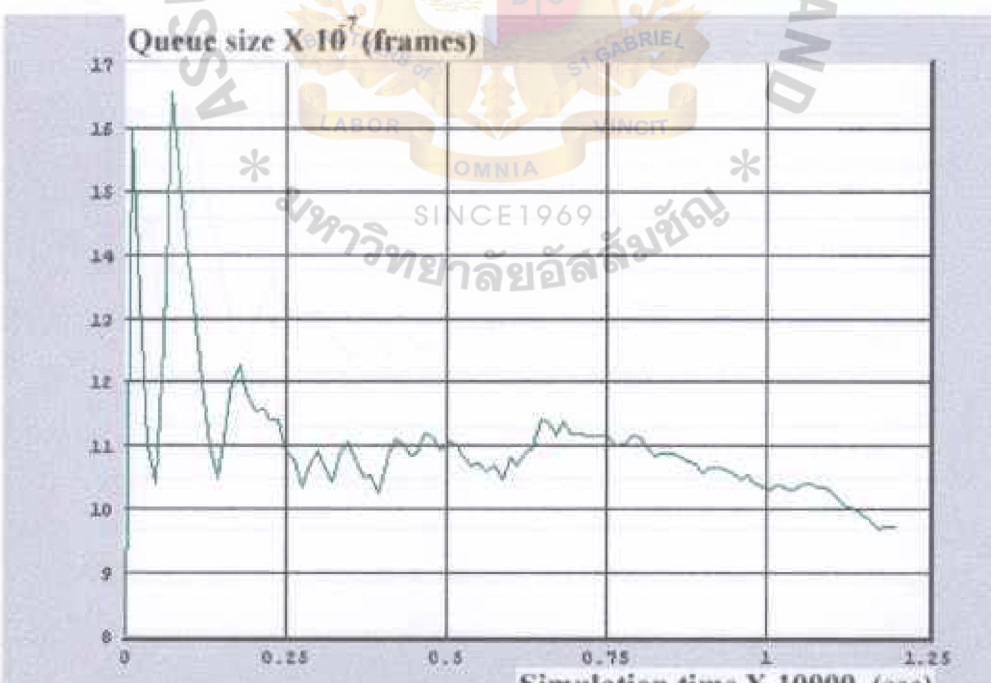


Figure 5.42 The graph of queue size on Monday by using G/D/1 queuing theory

Wednesday

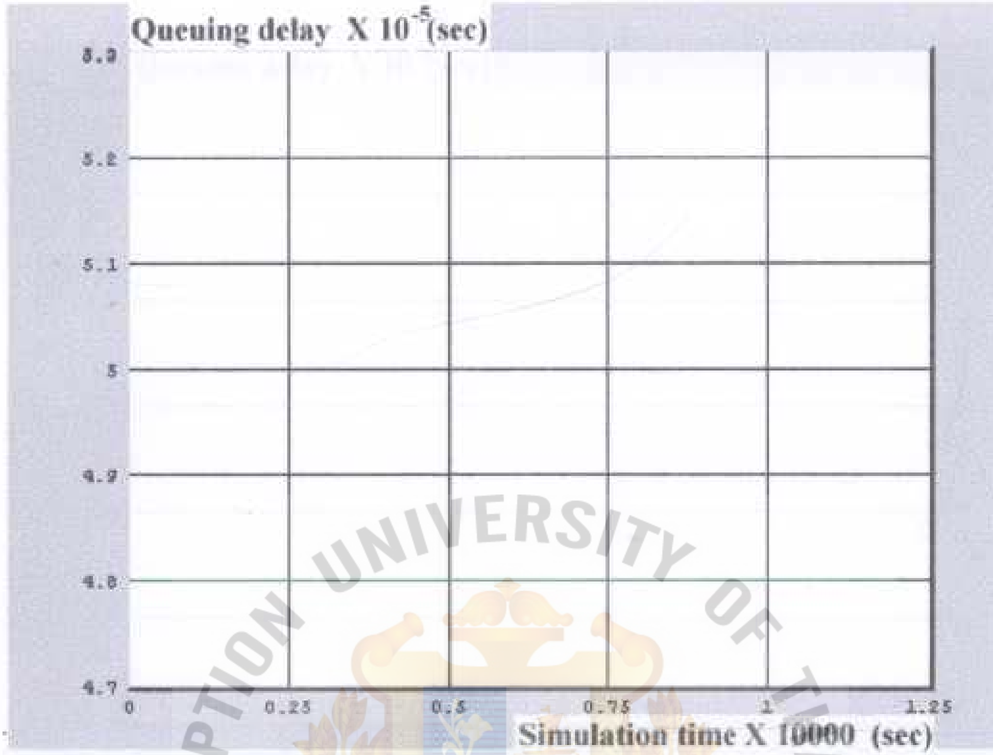


Figure 5.43 The graph of queuing delay on Wednesday by using G/D/1 queuing theory

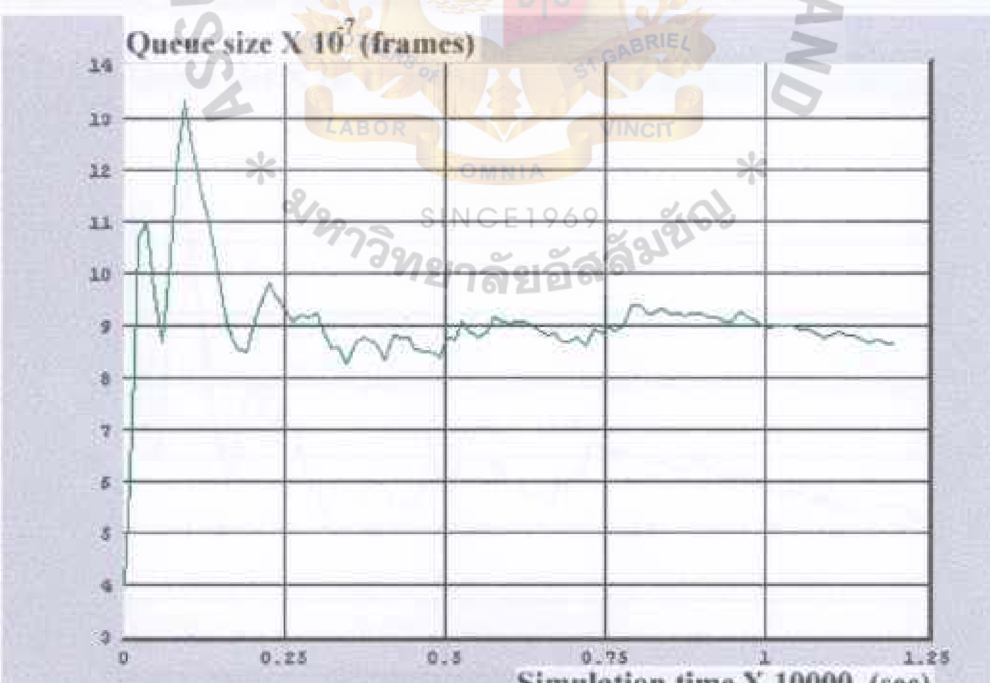


Figure 5.44 The graph of queue size on Wednesday by using G/D/1 queuing theory

Thursday

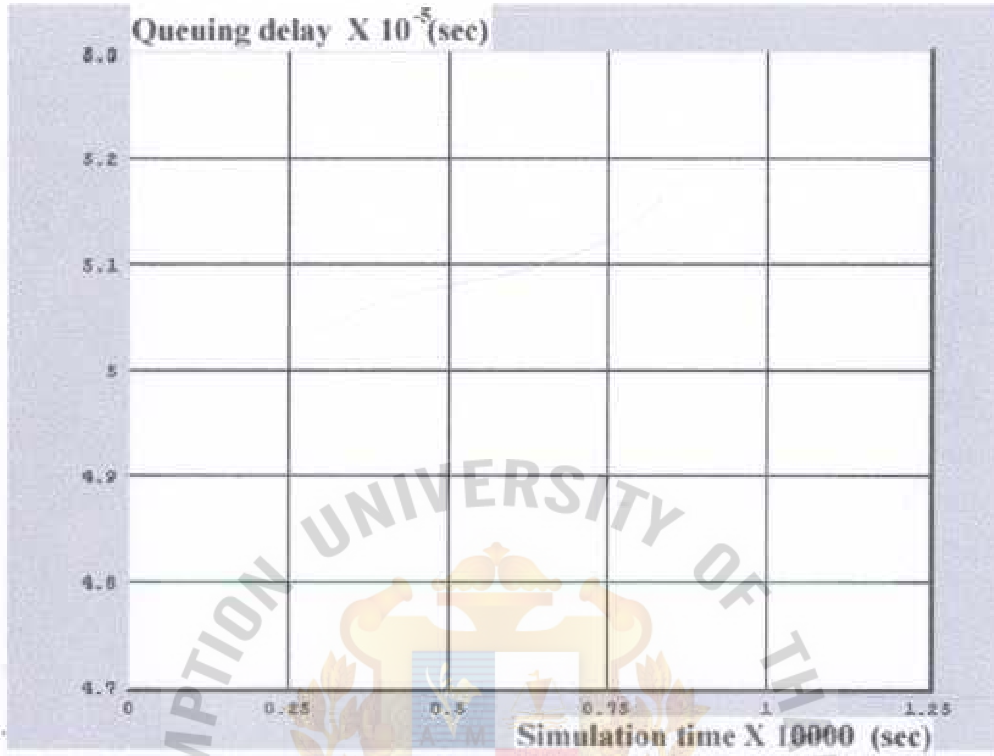


Figure 5.45 The graph of queuing delay on Thursday by using G/D/1 queuing theory

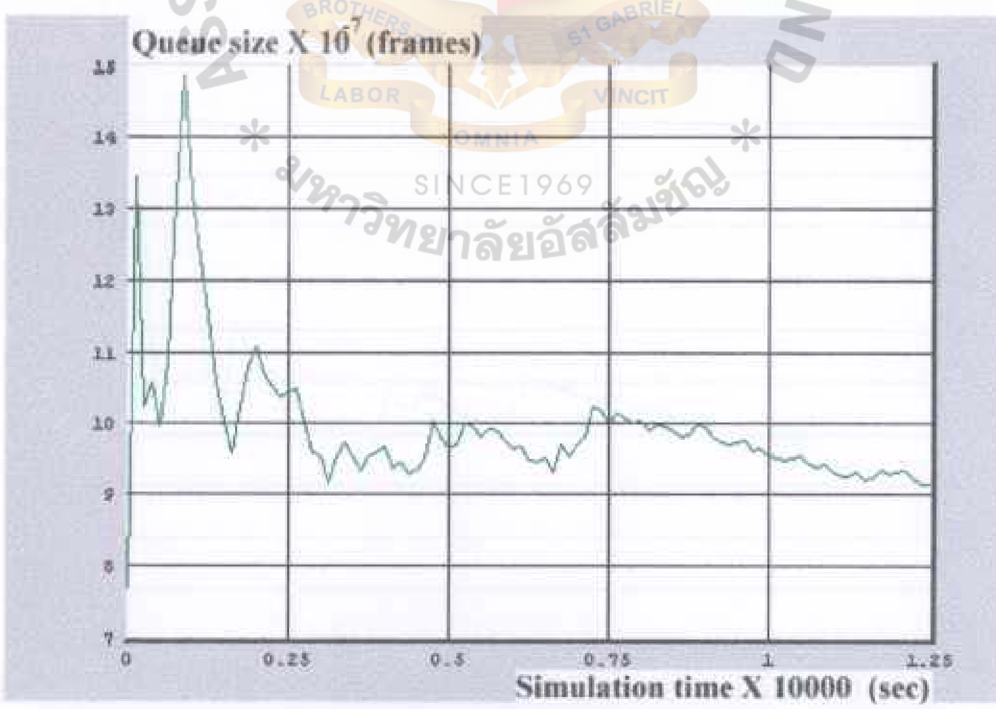


Figure 5.46 The graph of queue size on Thursday by using G/D/1 queuing theory

Friday

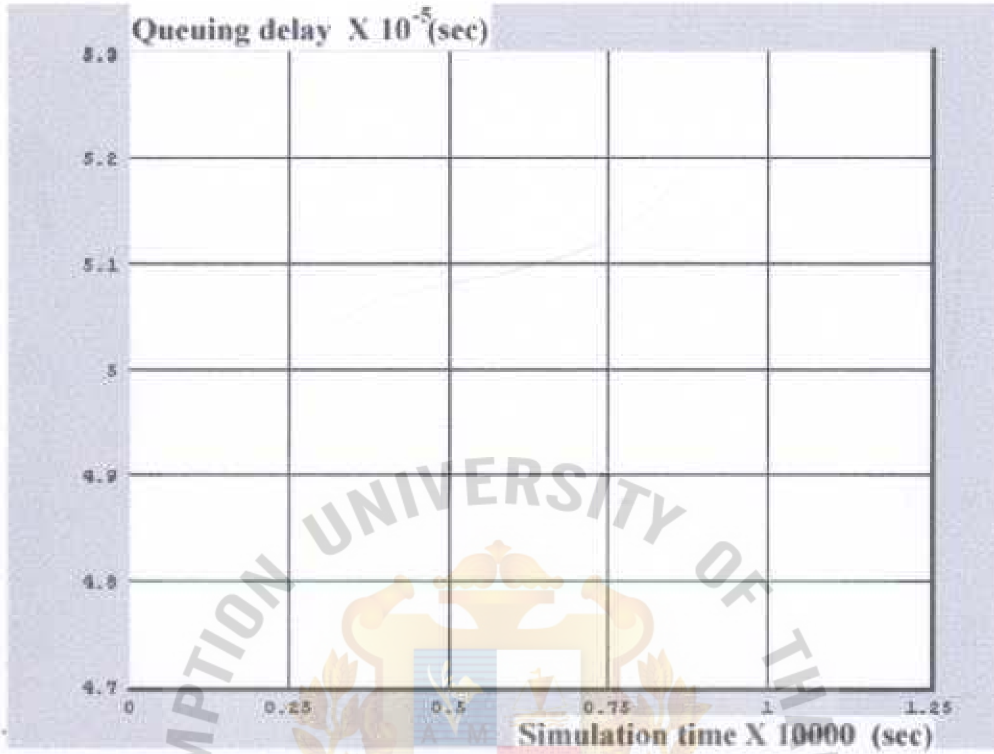


Figure 5.47 The graph of queuing delay on Friday by using G/D/1 queuing theory

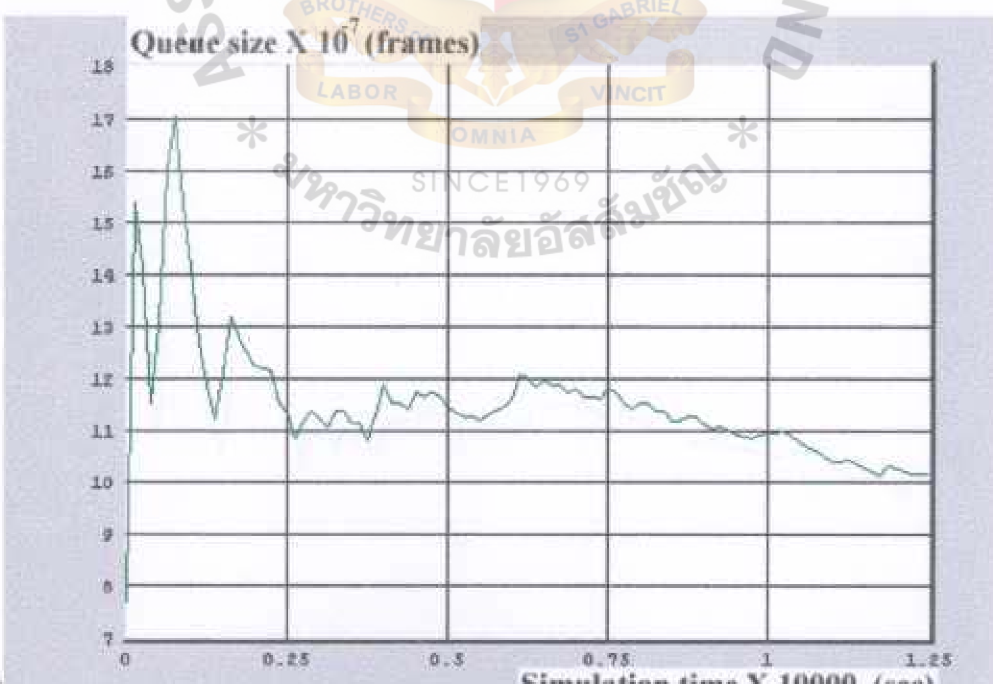


Figure 5.48 The graph of queue size on Friday by using G/D/1 queuing theory

Saturday

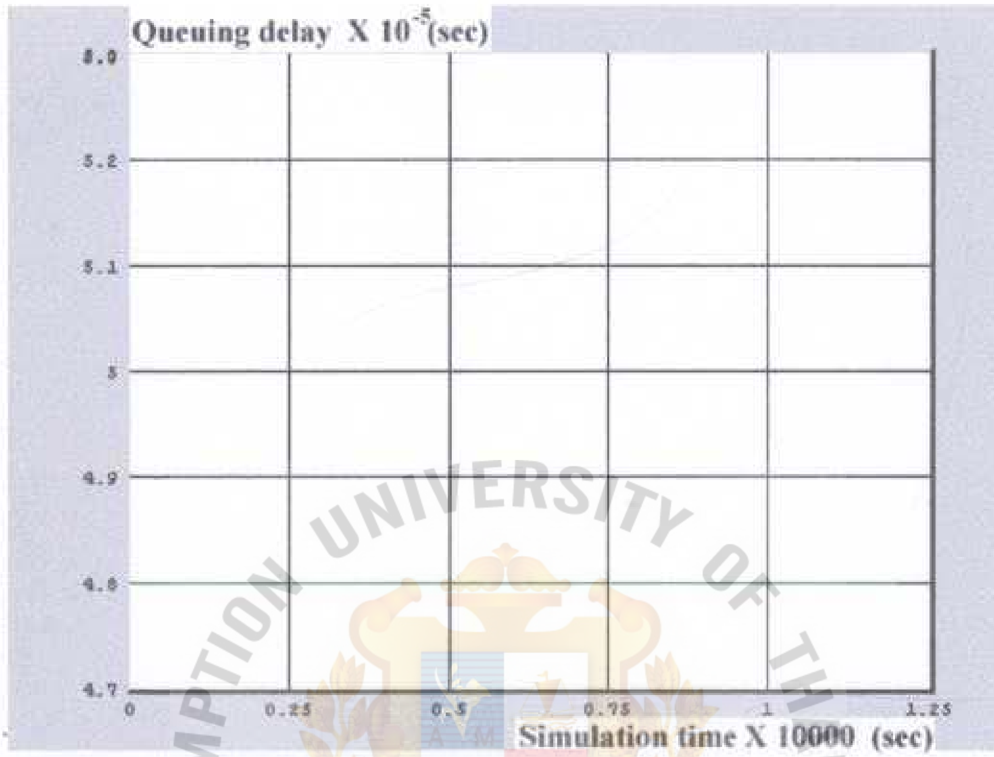


Figure 5.49 The graph of queuing delay on Saturday by using G/D/1 queuing theory

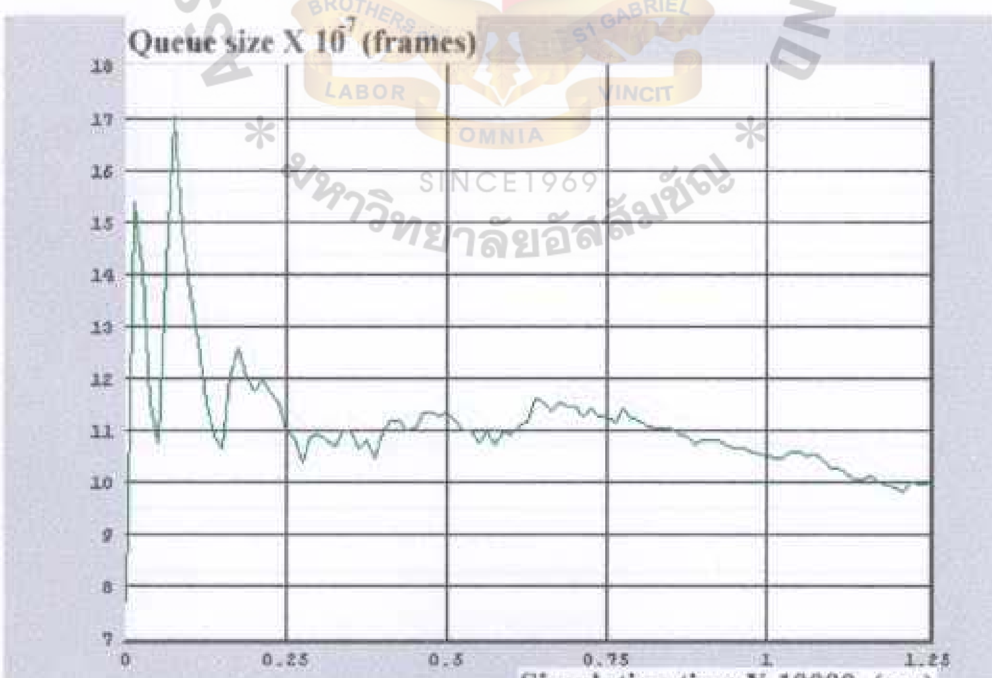


Figure 5.50 The graph of queue size on Saturday by using G/D/1 queuing theory

Sunday

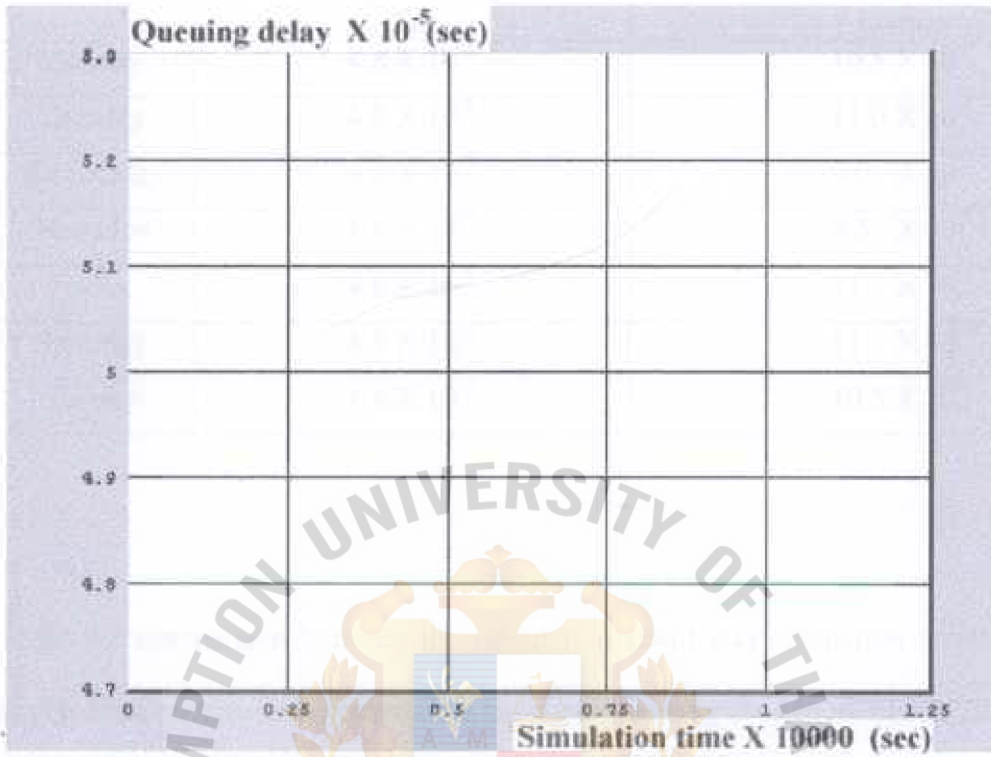


Figure 5.51 The graph of queuing delay on Sunday by using G/D/1 queuing theory

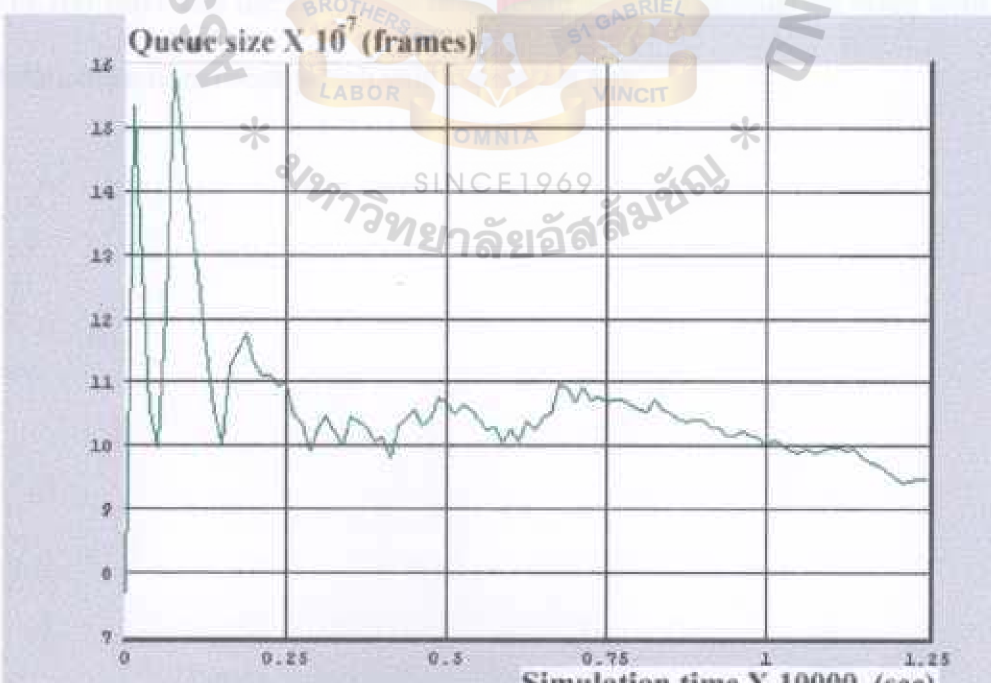


Figure 5.52 The graph of queue size on Sunday by using G/D/1 queuing theory

Table 5.3 The results of T and N in one week by using G/D/1 at steady state

Day	Total waiting time in queue (T) (Sec)	Expect Numbers of packets in queue(N) (Frames)
Monday	4.8×10^{-5}	10.5×10^{-7}
Tuesday	4.8×10^{-5}	11.0×10^{-7}
Wednesday	4.8×10^{-5}	9.0×10^{-7}
Thursday	4.8×10^{-5}	9.5×10^{-7}
Friday	4.8×10^{-5}	11×10^{-7}
Saturday	4.8×10^{-5}	11×10^{-7}
Sunday	4.8×10^{-5}	10.5×10^{-7}

From the comparison between the calculation result and simulation result which can conclude that Assumption University network is most suit to using the M/D/1 queue. So I will use this queuing theory to improving the performance of network by simulate again but changing the service rate to 100 Mb/s and use this result to compare with the calculation result with will tell us about the performance of network which will increase or not.

Monday

Figure 5.53 The graph of queuing delay on Monday when service rate is 100 Mb/s

Figure 5.54 The graph of queue size on Monday when service rate is 100 Mb/s

Tuesday

Figure 5.55 The graph of queuing delay on Tuesday when service rate is 100 Mb/s

Figure 5.56 The graph of queue size on Tuesday when service rate is 100 Mb/s

Wednesday

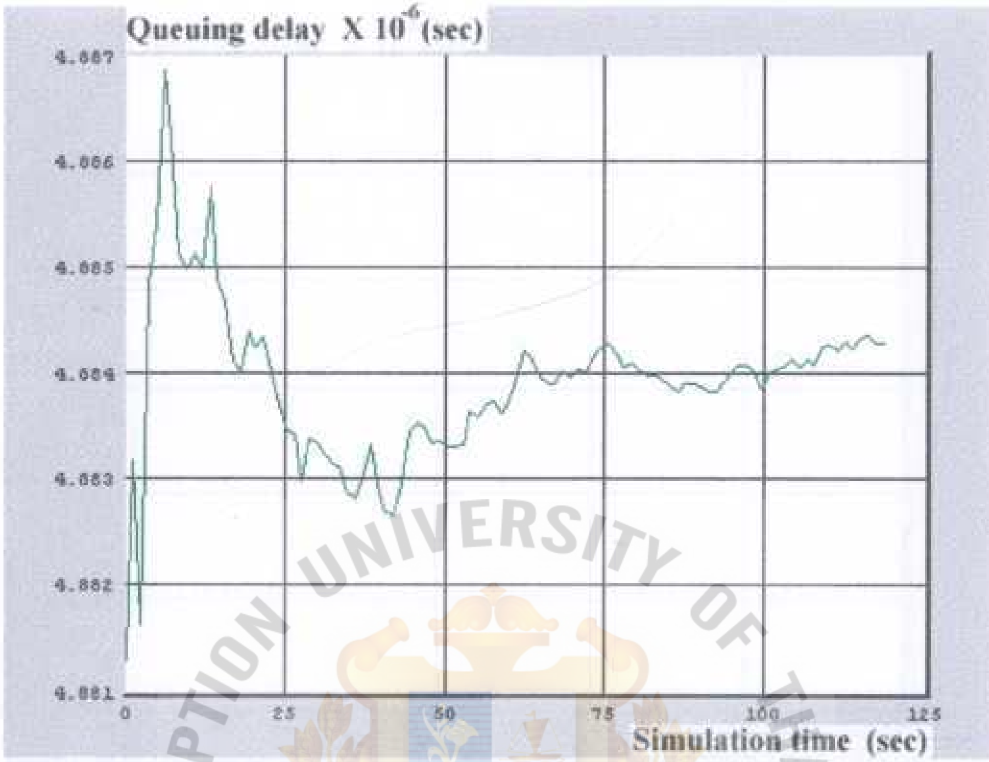


Figure 5.57 The graph of queuing delay on Wednesday when service rate is 100 Mb/s

Figure 5.58 The graph of queue size on Wednesday when service rate is 100 Mb/s

Thursday

Figure 5.59 The graph of queuing delay on Thursday when service rate is 100 Mb/s

Figure 5.60 The graph of queue size on Thursday when service rate is 100 Mb/s

Friday

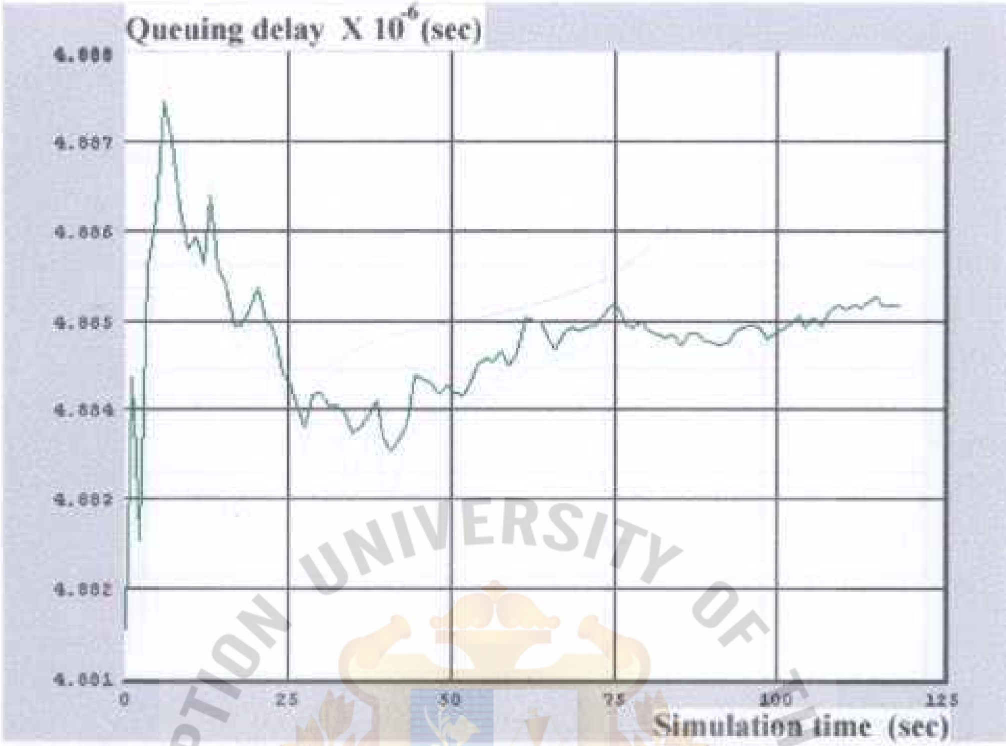


Figure 5.61 The graph of queuing delay on Friday when service rate is 100 Mb/s

Figure 5.62 The graph of queue size on Friday when service rate is 100 Mb/s

Saturday

Figure 5.63 The graph of queuing delay on Saturday when service rate is 100 Mb/s

Figure 5.64 The graph of queue size on Saturday when service rate is 100 Mb/s

Sunday

Figure 5.64 The graph of queuing delay on Sunday when service rate is 100 Mb/s

Figure 5.66 The graph of queue size on Sunday when service rate is 100 Mb/s

Table 5.4 The results of T and N in one week by using M/D/1 queuing and service equal to100Mb/s at steady state

Day	Total waiting time in queue (T) (Sec)	Expect Numbers of packets in queue(N) (Frames)
Monday	5.0×10^{-6}	0.03332
Tuesday	5.0×10^{-6}	0.03489
Wednesday	5.0×10^{-6}	0.03426
Thursday	5.0×10^{-6}	0.03353
Friday	5.0×10^{-6}	0.03460
Saturday	5.0×10^{-6}	0.03432
Sunday	5.0×10^{-6}	0.03342

CHAPTER 6. COMPLETE SIMULATION BY USING OPNET MODULE

This chapter present the simulation of the whole AUNet by using Opnet module with different from the Chapter 5 which using queuing system in Opnet program. The results are presented in the graphs of queuing delay and queuing size. They will be compared to the calculation and simulation results in Chapter 4 and 5, respectively.

Method to model the Assumption University Network

1.Getting Started

When creating a new network model, you must first create a new **project** and **scenario**. A project is a group of related scenarios that each explore a different aspect of the network design. Projects can contain multiple scenarios. Once you have created a new project, you can use the Startup Wizard to set the environment of a new scenario, including:

- Defining the initial topology of the network.
- Choosing the scale of the network.
- Selecting a background map for the network.
- Associating an object palette with the scenario.

Within the Startup Wizard, you can specify several aspects of a scenario. For this scenario, set up each Wizard dialog box as shown:

Table 6.1 The Wizard dialog box in Opnet program

Dialog Box Name	Value
Initial Topology	Default value: **Empty**
Choose Network Scale	**Campus**
Specify Size	Default size: **1000m x 2000m**
Select Grid Properties	Default spacing : **12.5 m**
Select Technology	I select the servers, routers, hubs and other devices that need in the network.
Review	Check values, then click **OK**

2.Creating the Network
For creating the network you can use several network building blocks:

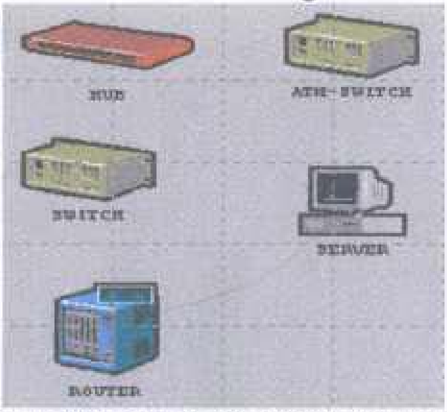


Figure 6.1 The picture of nodes in Opnet program

-Nodes - An OPNET representation of a real-world network object that can transmit and receive information. OPNET node models include objects such as routers, switches, hubs, and workstations.

- Links - A communication medium that connects nodes to one another. Links can represent electrical or fiber optic cables.

Figure 6.2 The picture of nodes in Opnet program

The network is now built and it ready to begin collecting statistics. However, first let verify link that correct or not by using verify link button.

Figure 6.3 The picture of verify link button

The model of ABAC network

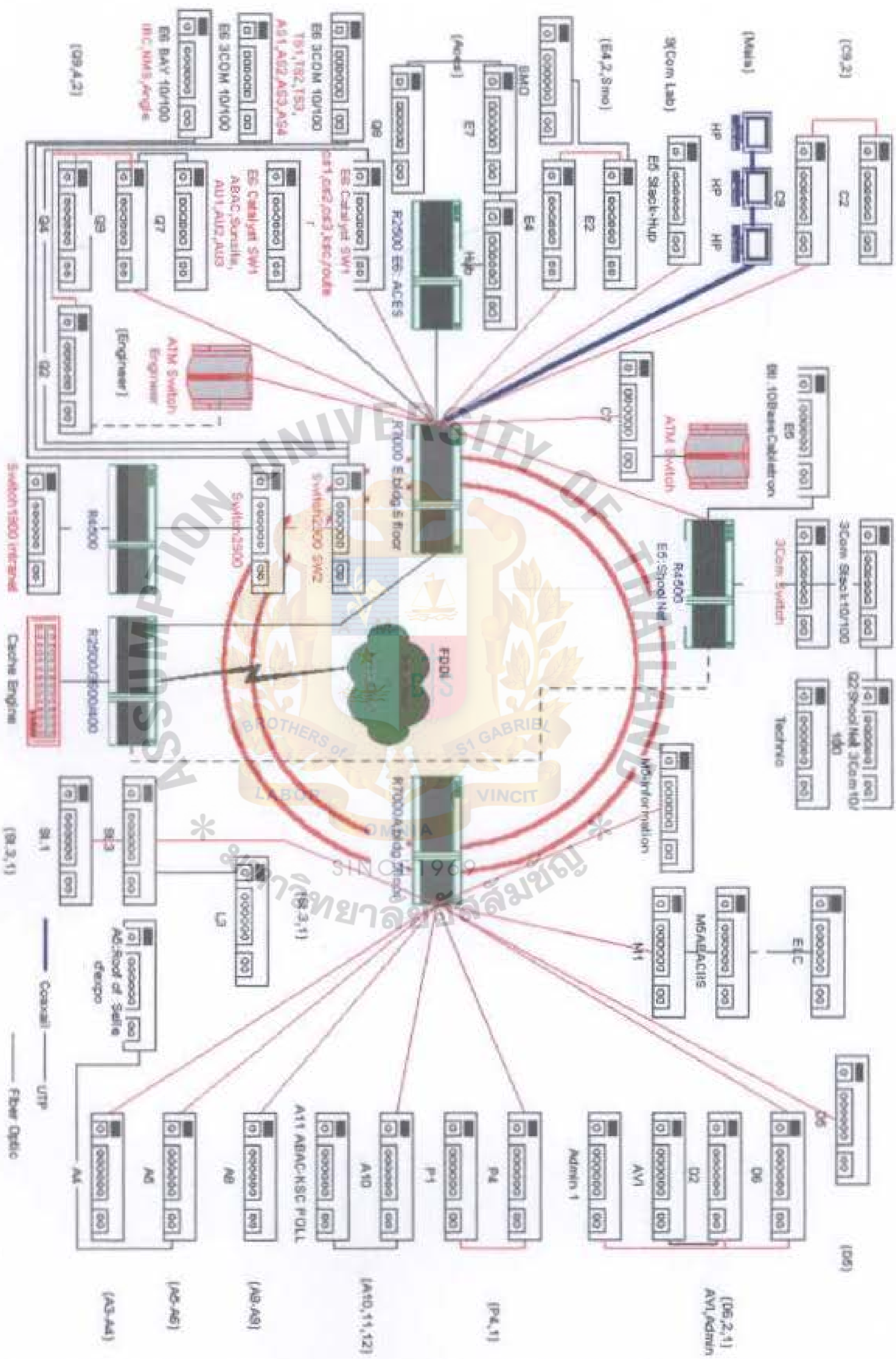


Figure 6.4 The model of ABAC network

The model of ABAC network when changing all networks to 100 Mb/s

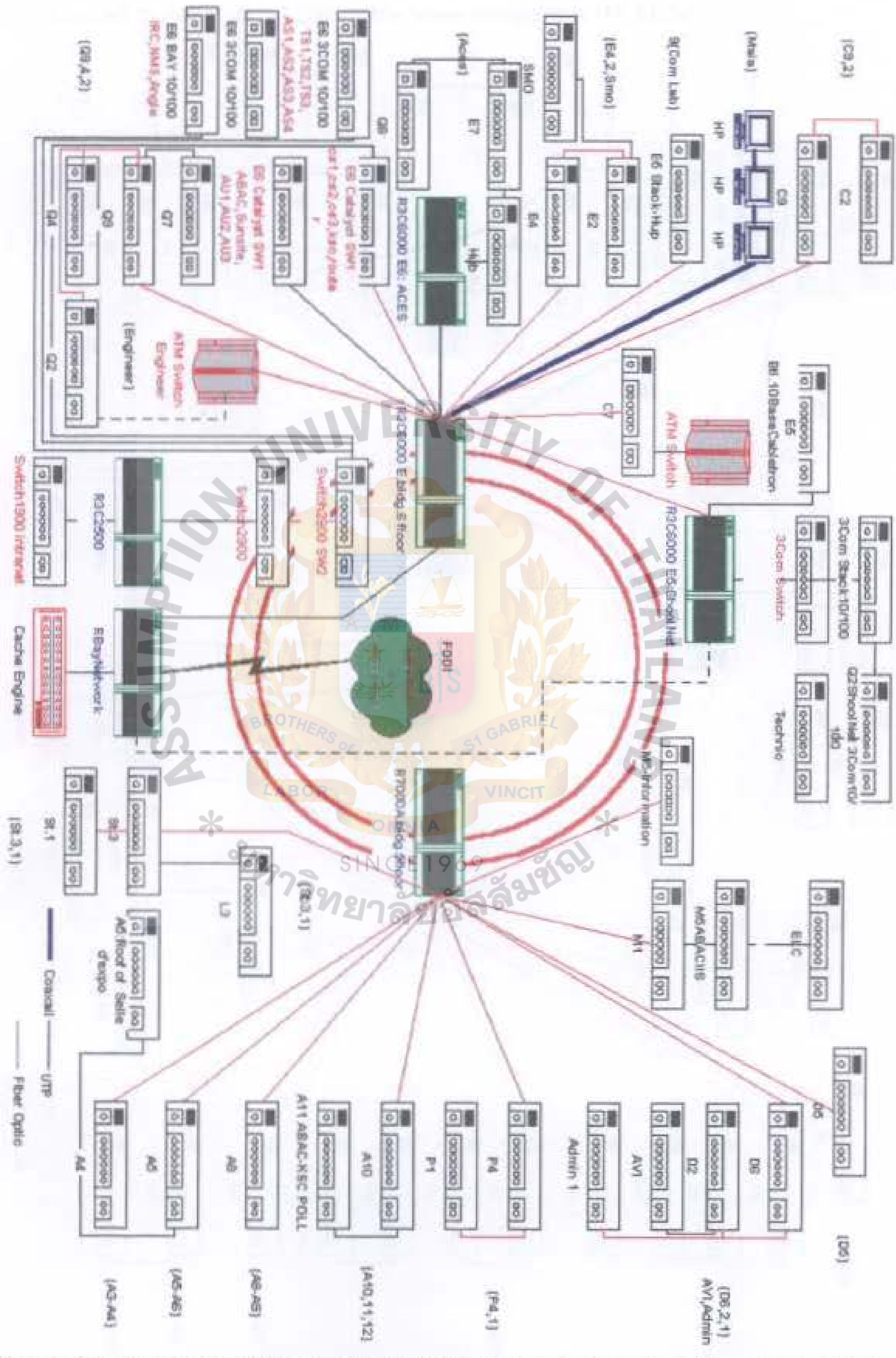


Figure 6.5 The figure of The model of ABAC network when changing all networks to 100 Mb/s

The model of ABAC network when changing service rate to 100 Mb/s but the network that connect to router at A.bldg are the same service rate (10 Mb/s).

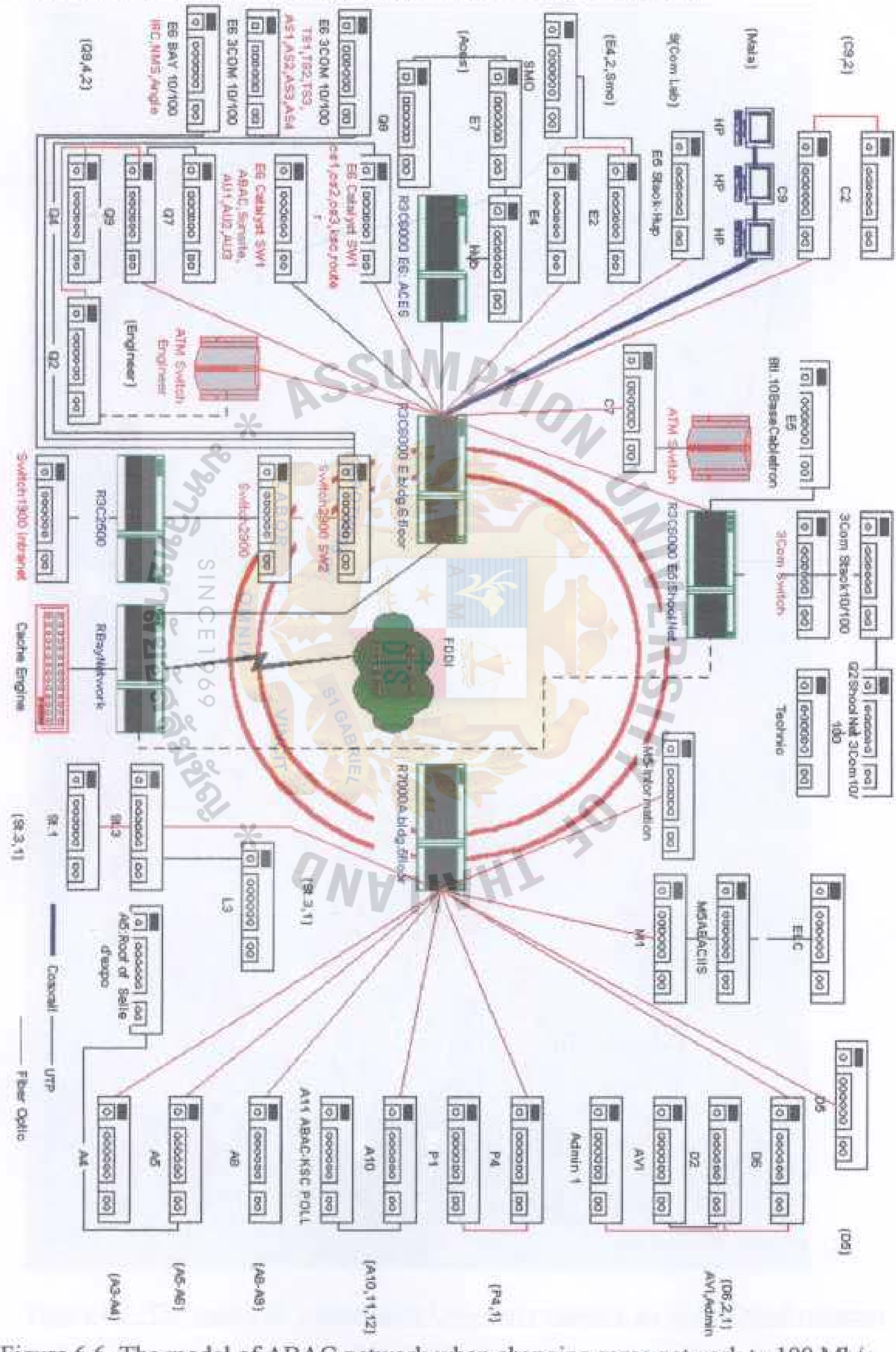


Figure 6.6 The model of ABAC network when changing some network to 100 Mb/s

The model of networkby using Opnet program
This is the model of Assumption University network by using Opnet program

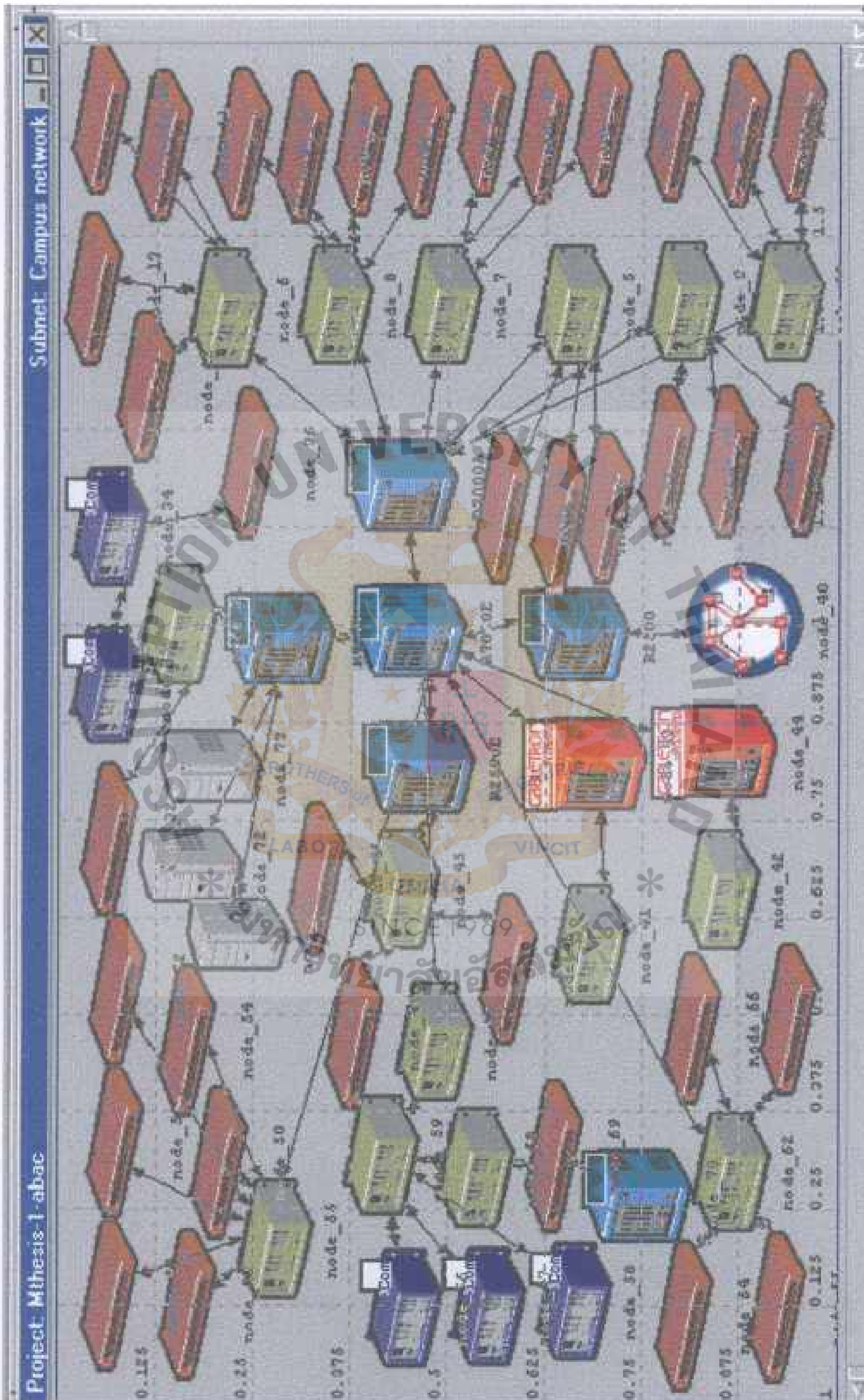


Figure 6.7 The model of Assumption University network by using Opnet program

This is the model of ABAC network that changing all networks to be 100 Mb/s by using Opnet program.

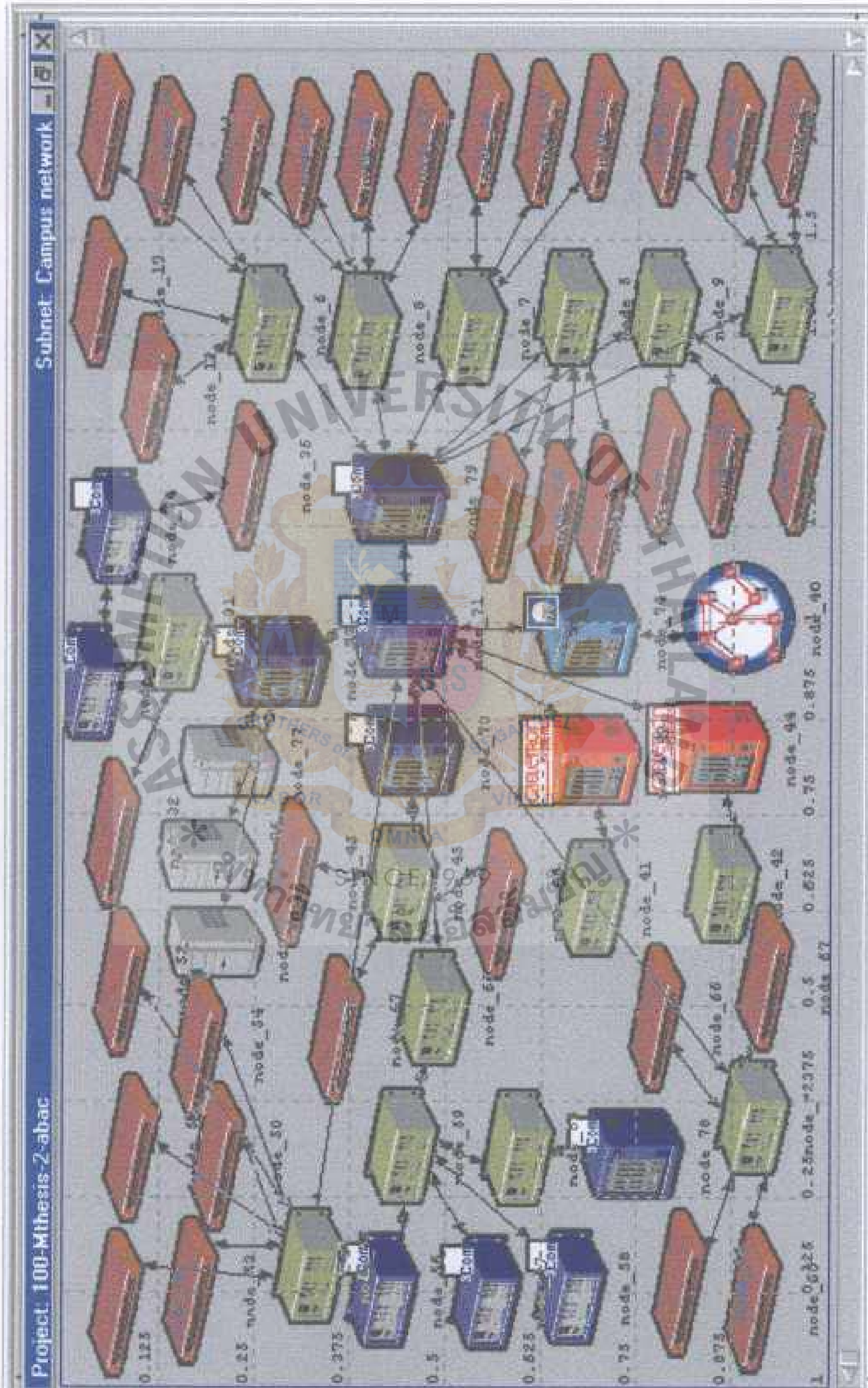


Figure 6.8 The model of ABAC network that changing all networks to be 100 Mb/s by using Opnet program.

This is the model of ABAC network by using Opnet program which change service rate to be 100 Mb/s, but network that connect to router at A .bldg are same service rate at 10 Mb/s.

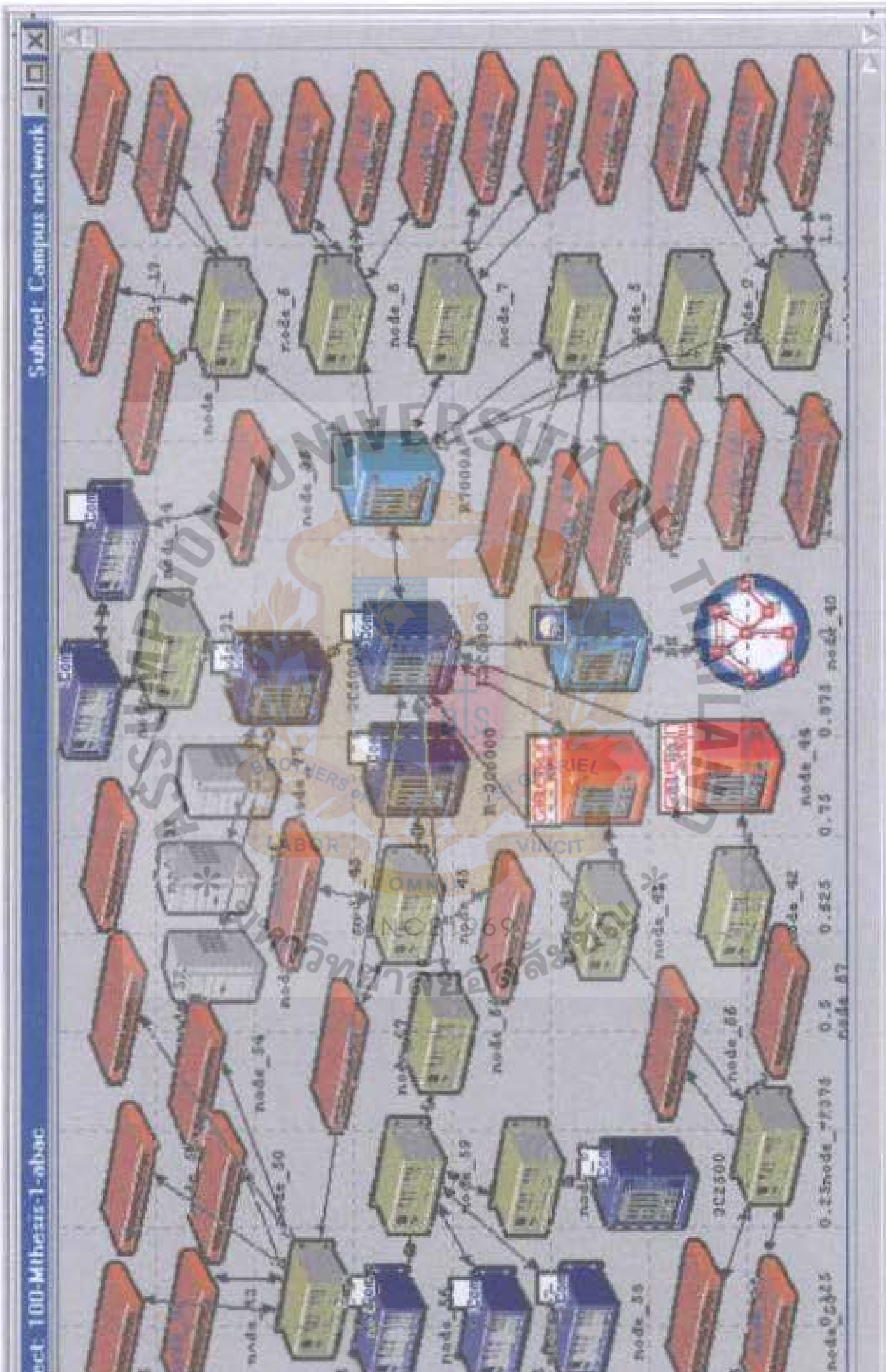


Figure 6.9 The model of ABAC network which changing service rate to 100 Mb/s except the network that connect to router at A bldg are same service rate (10 Mb/s)

3. Collecting Statistics

Now that you have created the network, you should decide which statistics you need to collect to answer the questions presented for this network, namely: To answer these questions, I will collect the queuing delay and packet size because they are key statistic that affects the performance of the entire network . After that you choose run Simulation action button

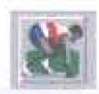


Figure 6.10 The picture of simulation button in Opnet program

4. Viewing Results

To view the statistics queuing delay and incoming packet size. You select the view result of queuing size (incoming packets) and queuing delay (incoming packets) to view the results.

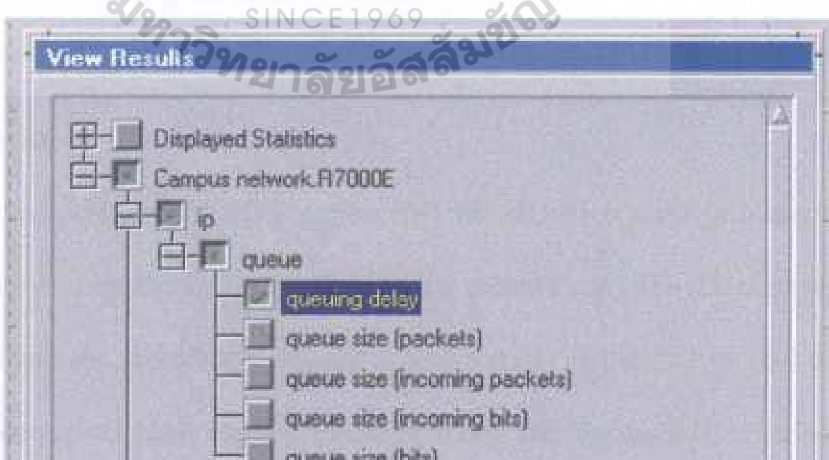


Figure 6.11 The picture of view result in Opnet program

CHAPTER 7.DISCUSSION ON THE RESULTS

This chapter is divided into 2 main parts which are the discussions on comparing the calculation and simulation results (from chapter 4,5,and 6), and the suggestion on improving the performance of the network in Assumption University.

7.1 Results Comparison

To model the network, the three queuing parameters should be known. They are the arrival process, the service statistics, and the number of servers. From the measurement results of the Assumption University network it can be seen that there is one server (a single transmission line). Also, the packet size is almost constant at 60 Bytes so the service statistics should be deterministic. And therefore, the only factor left to be determined is the type of arrival process.

It is assumed that the queuing system of the network should be one of the followings.

- M/D/1, if interarival times are exponentially distributed.
- D/D/1, if interarrival time is deterministic.
- G/D/1, if interarrival times are of general distribution.

7.1.1 M/D/1 queuing system

If the queuing system in AuNet is M/D/1 it means that the arrival process is Memoryless (M) where the interarrival time is exponential distributed. The comparison between the measurement of the interarrival time and the probability density function (pdf) of the exponential distribution has shown that the interarrival time can be modeled using the exponential distribution. The packet length in AuNet is constant at 60 Bytes or the service statistics is deterministic. Then the two important characteristics of queuing system can be found: the expected number of customers in the system (N) and the total delay (T). Following are the results comparison from calculation, Opnet simulation and the Opnet module simulation.

Table 7.1 The Average Number of Customers in the System (N) Results Comparison from Calculation, Opnet Simulation and Opnet Module Simulation.

	Calculation (Frames)	Opnet Simulation (Frames)	Module Simulation Opnet (Frames)
Monday	0.4066	0.4074	0.1061
Tuesday	0.4213	0.4321	0.1061
Wednesday	0.4212	0.4220	0.1061
Thursday	0.4099	0.4100	0.1061
Friday	0.4268	0.4276	0.1061
Saturday	0.4221	0.4229	0.1061
Sunday	0.4082	0.4089	0.1061

Table 7.2 The Total Delay in the System (T) Results Comparison from calculation, Opnet Simulation and Opnet module simulation.

	Calculation (sec)	Opnet Simulation (sec)	Module Simulation Opnet (sec)
Monday	5.970×10^{-5}	6.000×10^{-5}	2.743×10^{-5}
Tuesday	6.048×10^{-5}	6.027×10^{-5}	2.743×10^{-5}
Wednesday	6.015×10^{-5}	6.002×10^{-5}	2.743×10^{-5}
Thursday	5.977×10^{-5}	6.000×10^{-5}	2.743×10^{-5}
Friday	6.033×10^{-5}	6.008×10^{-5}	2.743×10^{-5}
Saturday	6.018×10^{-5}	6.002×10^{-5}	2.743×10^{-5}
Sunday	5.971×10^{-5}	6.000×10^{-5}	2.743×10^{-5}

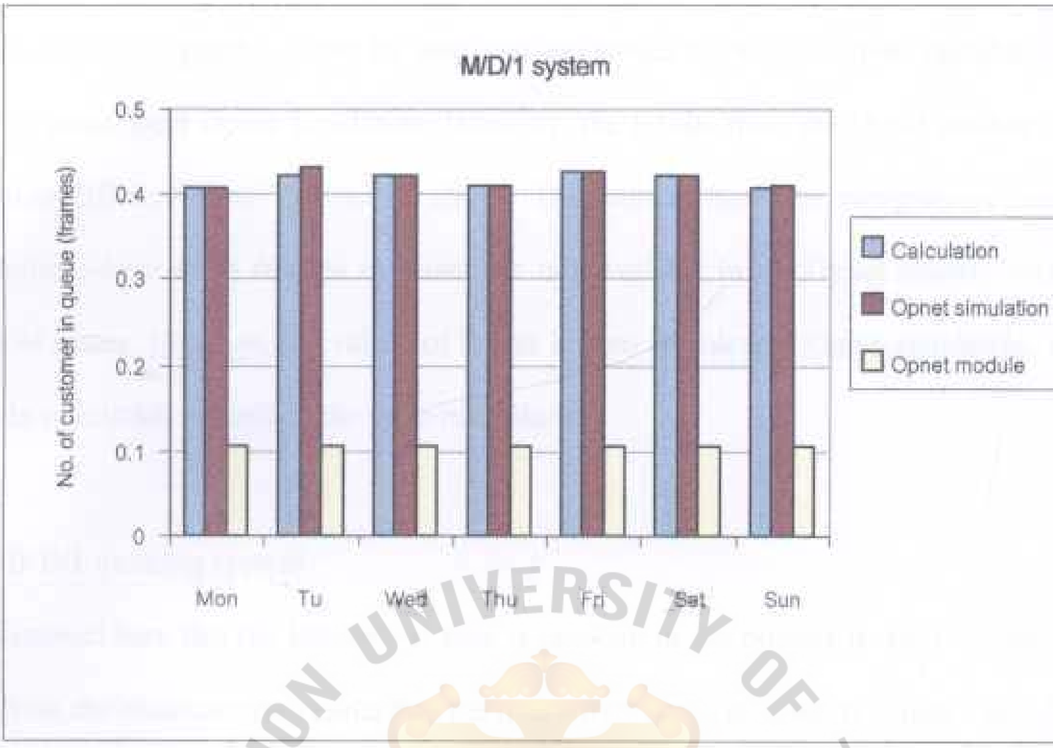


Figure 7.1. The Average Number of Customers in the System (N) Results Comparison from Calculation, Opnet Simulation and Opnet Module Simulation.

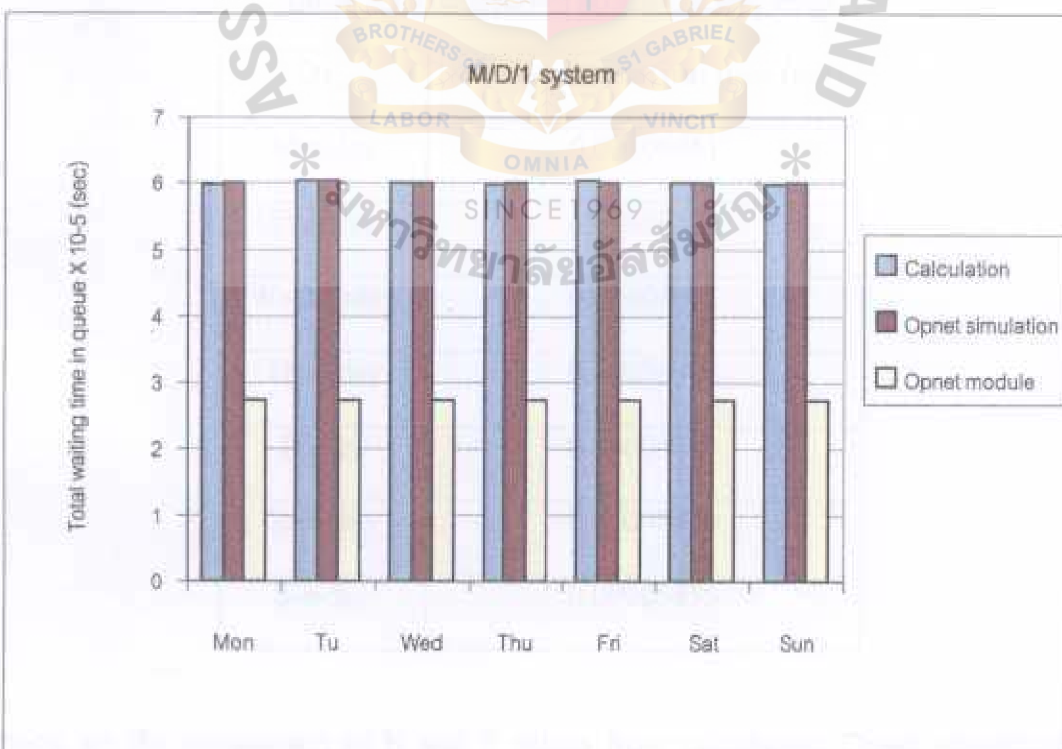


Figure 7.2 The Total Delay in the System (T) Results Comparison from Calculation, Opnet Simulation and Opnet Module Simulation.

From the graphs, it can be seen that the values of N and T from calculation are very close to those from Opnet simulation. However, the results from the Opnet module simulation are quite different from the results above. This comes from the compromise made during simulation where some devices in Aunet are not available in the Opnet module such as some series of router. However, the values of N and T from calculation, Opnet simulation, and Opnet module simulation are still of the same magnitude.

7.1.2 D/D/1 queuing system

It is assumed here that the interarrival time is constant or the process is deterministic. It can be seen from the measurement results that the interarrival times are almost constant and fall mostly between the 0.00006 and 0.00007 sec values. Therefore the weighted average of the interarrival times are calculated and used. The results can be seen below.

Table 7.3 The interarrival time in one week

Day	Average Interarrival time (sec)
Monday	0.00006461
Tuesday	0.00006466
Wednesday	0.00006462
Thursday	0.00006453
Friday	0.00006463
Saturday	0.00006466
Sunday	0.00006455

Following are the comparison of N and T values from calculation, Opnet simulation and the Opnet module simulation.

Table 7.4 The Average Number of Customers in the System (N) Results Comparison from Calculation, Opnet Simulation and Opnet Module Simulation.

	Calculation (Frames)	Opnet Simulation (Frames)	Module Simulation Opnet (Frames)
Monday	$N \leq 0.0743$	0.7476	0.1061
Tuesday	$N \leq 0.0743$	0.7423	0.1061
Wednesday	$N \leq 0.0743$	0.7428	0.1061
Thursday	$N \leq 0.0743$	0.7438	0.1061
Friday	$N \leq 0.0743$	0.7426	0.1061
Saturday	$N \leq 0.0743$	0.7423	0.1061
Sunday	$N \leq 0.0743$	0.7438	0.1061

Table 7.5 The Total Delay in the System (T) Results Comparison from Calculation, Opnet Simulation and Opnet Module Simulation.

	Calculation (sec)	Opnet Simulation (sec)	Module Simulation Opnet (sec)
Monday	$T \leq 4.8 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Tuesday	$T \leq 4.8 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Wednesday	$T \leq 4.8 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Thursday	$T \leq 4.8 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Friday	$T \leq 4.8 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Saturday	$T \leq 4.8 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Sunday	$T \leq 4.8 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}

Figure 7.3 The Average Number of Customers in the System (N) Results Comparison from Calculation, Opnet Simulation and Opnet Module Simulation.

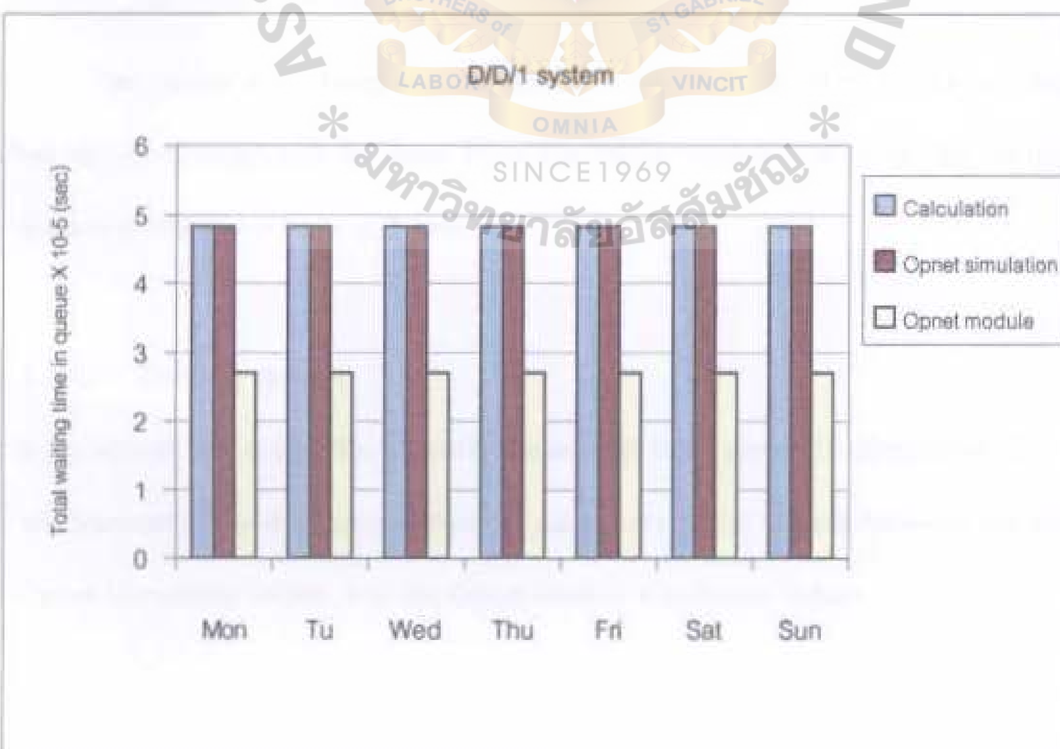


Figure 7.4 The Total Delay in the System (T) Results Comparison from Calculation, Opnet simulation and Opnet module simulation.

The calculation results of N and T are the upper bound values or the heavy load system (Utilization nearly or equal to 1) so the results from calculation are the maximum results that will be in the system. But the traffic load system in Aunet is not the heavy because the Utilization is only about 0.33

Table 7.6 The Utilization in AuNet in one week

	Utilization
Monday	0.32
Tuesday	0.34
Wednesday	0.33
Thursday	0.33
Friday	0.34
Saturday	0.33
Sunday	0.33

The values of T from calculation are close to those from the Opnet simulation and within the same magnitude as those from the Opnet module. However, the values of N from these three methods are quite different.

7.1.3 G/D/1 queuing system

Here the arrival process of the network is assumed to be generally distributed. The table shows the comparison of the average numbers of customers in the system between calculation values, the Opnet simulation values, and the Opnet module simulation values.

Table 7.7 The Average Number of Customers in the System (N) Results Comparison from Calculation, Opnet Simulation and Opnet Module Simulation.

	Calculation (frames)	Opnet Simulation (frames)	Module Simulation Opnet (Frames)
Monday	$N \leq 0.3576$	10.5×10^{-7}	0.1061
Tuesday	$N \leq 0.3428$	11×10^{-7}	0.1061
Wednesday	$N \leq 0.3365$	9×10^{-7}	0.1061
Thursday	$N \leq 0.3297$	9.5×10^{-7}	0.1061
Friday	$N \leq 0.3399$	11×10^{-7}	0.1061
Saturday	$N \leq 0.3297$	11×10^{-7}	0.1061
Sunday	$N \leq 0.3286$	10.5×10^{-7}	0.1061

Table 7.8 The Total Delay in the System (T) Results Comparison from Calculation, Opnet Simulation and Opnet Module Simulation.

	Calculation (sec)	Opnet Simulation (sec)	Module Simulation Opnet (sec)
Monday	$T \leq 4.80765 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Tuesday	$T \leq 4.80757 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Wednesday	$T \leq 4.80732 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Thursday	$T \leq 4.80908 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Friday	$T \leq 4.80532 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Saturday	$T \leq 4.80908 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}
Sunday	$T \leq 4.8073 \times 10^{-5}$	4.8×10^{-5}	2.743×10^{-5}

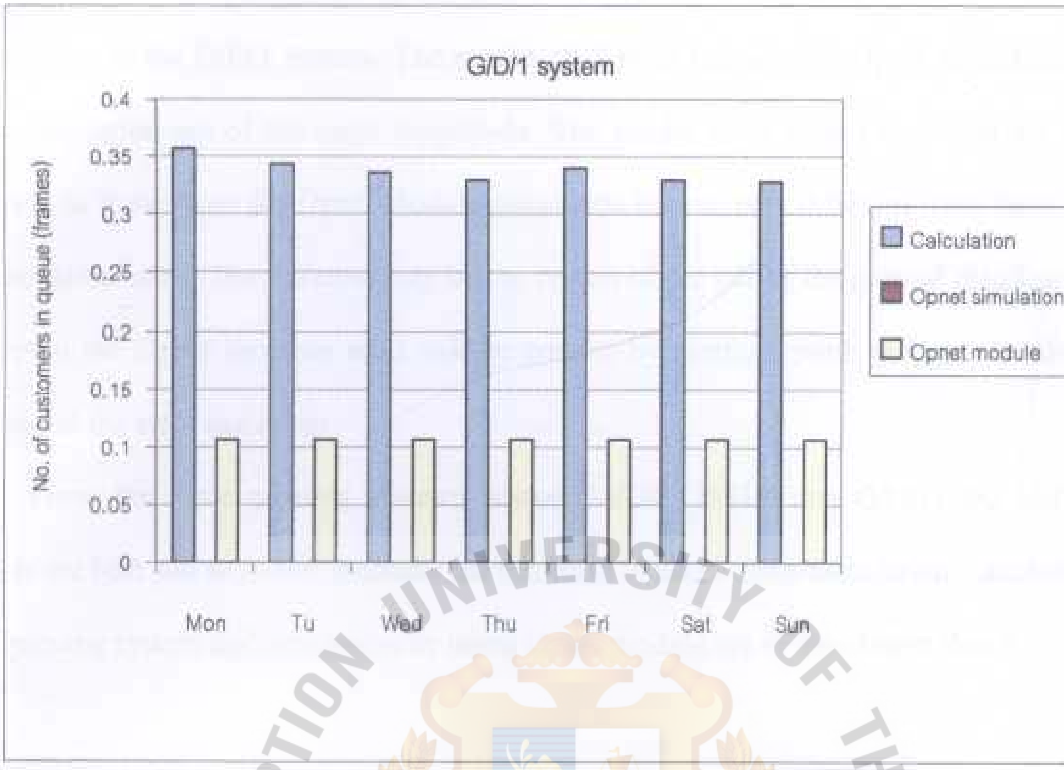


Figure 7.5 The Average Number of Customers in the System (N) Results Comparison from Calculation, Opnet Simulation and Opnet Module simulation.

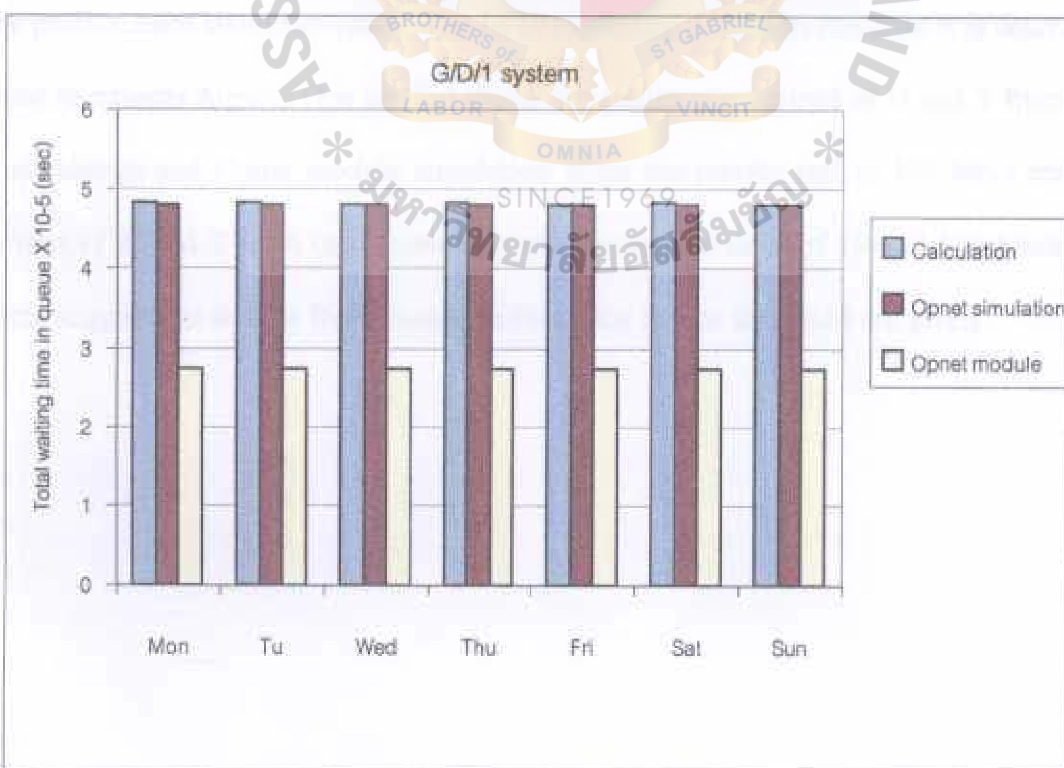


Figure 7.6 The Total Delay in the System (T) Results Comparison from Calculation, Opnet simulation and Opnet module simulation.

The calculation results of N and T are the upper bound values for the heavy load system same as those in the D/D/1 system. The results of T from calculation, Opnet simulation and Opnet module simulation are of the same magnitude. The results of N from calculation are of the same magnitude as those from the Opnet module simulation but are very different from those acquired by the Opnet simulation. The different may be the reason of the pdf of the general distribution which is not exist in the Opnet program so it will be created by plotting graph and the use this results to simulate and the error can occur.

From the three queuing systems above (M/D/1, D/D/1 and G/D/1) the M/D/1 queuing system is the best suit to Aunet. Because the results of N and T from calculation, simulation by using Opnet queuing system and simulation by using Opnet module are of the closest match.

7.2 Improving the performance of network

Currently, the service rate of AuNet is 10 Mb/s. If the service rate is increased to 100 Mb/s the network performance should increase. The M/D/1 queuing is used in this case it is determined that it is the best represents AuNet. This section shows the results comparison of N and T from calculation, Opnet simulation and Opnet module simulation when the service rate is 100 Mb/s and the results comparison of N and T from calculation become the service rates of 10 and 100 Mb/s. And at the end, some suggestions as how the network performance can be increased are given.

Table 7.9 The Average Number of Customers in the System (N) Results Comparison from Calculation, Opnet Simulation and Opnet Module Simulation at 100 Mb/s.

	Calculation (Frames)	Opnet Simulation(Frames)	Simulation Opnet module (Frames)
Monday	0.03326	0.03332	0.01926
Tuesday	0.03483	0.03489	0.01926
Wednesday	0.0342	0.03426	0.01926
Thursday	0.03347	0.03353	0.01926
Friday	0.03454	0.03460	0.01926
Saturday	0.03425	0.03432	0.01926
Sunday	0.03336	0.03342	0.01926

Table 7.10 The Total Delay in the System (T) Results Comparison from Calculation, Opnet Simulation and Opnet Module Simulation at 100 Mb/s.

	Calculation (sec)	Opnet Simulation (sec)	Module Simulation Opnet (sec)
Monday	4.881×10^{-6}	5×10^{-6}	2.94×10^{-6}
Tuesday	4.885×10^{-6}	5×10^{-6}	2.94×10^{-6}
Wednesday	4.883×10^{-6}	5×10^{-6}	2.94×10^{-6}
Thursday	4.881×10^{-6}	5×10^{-6}	2.94×10^{-6}
Friday	4.884×10^{-6}	5×10^{-6}	2.94×10^{-6}
Saturday	4.883×10^{-6}	5×10^{-6}	2.94×10^{-6}
Sunday	4.881×10^{-6}	5×10^{-6}	2.94×10^{-6}

Figure 7.7 The Average Number of Customers in the System (N) Results Comparison from Calculation, Opnet Simulation and Opnet Module Simulation at 100 Mb/s.

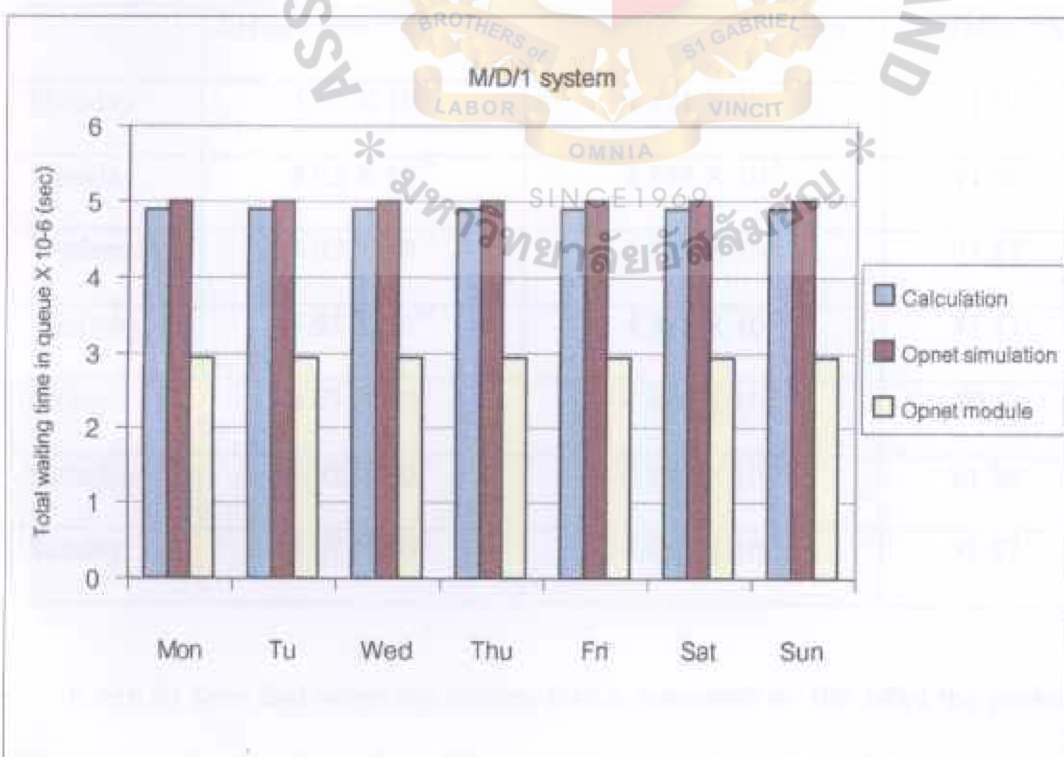


Figure 7.8 The Total delay in the system (T) results comparison from calculation, Opnet simulation and Opnet Module Simulation at 100 Mb/s.

The results of N and T from calculation, Opnet simulation and Opnet module simulation still are of the same magnitude with the service rate now 100 Mb/s.

Table 7.11 The Calculation Results Comparison of N become 10 and 100 Mb/s service rate.

	Service rate = 10 Mb/s	Service rate = 100 Mb/s	Decrease (%)
Monday	0.4066	0.03356	91.82
Tuesday	0.4313	0.03483	91.90
Wednesday	0.4212	0.03420	91.88
Thursday	0.4099	0.03347	91.83
Friday	0.4268	0.03454	91.9
Saturday	0.4221	0.03425	91.88
Sunday	0.4082	0.03336	91.82

Table 7.12 The Calculation Results Comparison of T become 10 and 100 Mb/s service rate.

	Service rate = 10 Mb/s	Service rate = 100 Mb/s	Decrease (%)
Monday	5.97×10^{-5}	4.881×10^{-6}	91.82
Tuesday	6.05×10^{-5}	4.885×10^{-6}	91.90
Wednesday	6.02×10^{-5}	4.883×10^{-6}	91.88
Thursday	5.98×10^{-5}	4.881×10^{-6}	91.83
Friday	6.03×10^{-5}	4.884×10^{-6}	91.9
Saturday	6.02×10^{-5}	4.884×10^{-6}	91.88
Sunday	5.97×10^{-5}	4.881×10^{-6}	91.82

It can be seen that when the service rate is increased to 100 Mb/s the performance of the network is improved as the values of N and T decrease about 92%. If the service rate of the entire network is increased to be 100 Mb/s it would take a large budget. So it more economical if only parts of network with many users such as the Computer Lab in E and C building and some networks which have ATM switch are modified. An important network link that should be changed to 100 Mb/s is the network link between the 7000 and the 2500 router in the 6^{th} floor of the E building since this is the bottleneck of the network before connecting to the Internet. Nevertheless the Internet traffic through put in AuNet is limited by the maximum service rate to the Internet Service provider (ISP). This problem can be solved by connecting another lease line to the ISP but this would also require a large budget too.

CHAPTER 8. CONCLUSION

In this paper it consists of 6 parts which are

The first part is Introduction with include this topic

- Purpose of this thesis
- Outline of this paper
- What you get from this thesis

The second part is Background Knowledge that include of many topic which are:

- A Brief History of the Internet.
- What is TCP/IP ?
- Components of the Internet.
- A Brief History of the Internet in Thailand.
- Work previous done which has the topic similar to this thesis topic.
- Queuing theory that use in this thesis.

The third part is about the results of measurement Internet traffic in ABAC by using the Sniffer Network Analyzer. The results are presented by using graph which are the comparison between the results of measurement and the results when using the Probability Density Function (pdf) of the Exponential distribution This is because to find the arrival statistic is nearly Memoryless (M) or not that it will useful for model the queuing system.

The fourth part is Calculation which using many type of Queuing system.In ABAC network which almost of packet size is 60 Byte and there is only one server (transmission line) so the queuing system that should use are:

- M/D/1 Queuing system
- D/D/1 Queuing system
- G/D/1 Queuing system

and present the results of calculation when using the service rate10 and 100 Mb/s.

The fifth part is the Simulation results which using the Opnet program. It present graphs of the expected number of packet in system (N) and the total waiting time in the system (T). The graphs are the result of using Opnet program to model each of above Queuing systems at service rate and 10 and 100 Mb/s and model the ABAC Network too.

The last parts is Discussion which contain three topic. The first is comparison results of calculation, simulation and model of Assumption University network in each Queuing system by using graph or table to present. The second is improving the performance of network by using the results from Opnet program. The last one is the problem during model ABAC network.

From the comparison results between calculation, simulation by using measurement statistics and complete simulation using Opnet module you will see that network in ABAC is more suitable for M/D/1 queuing theory than other queuing theory. Although the calculation result by using M/D/1 queuing theory and simulation results by using Opnet module are not exactly the same. The cause of this problem may be about some equipment in ABAC network doesn't same model and some equipment doesn't has in Opnet model. This problem can be solve by adapt some path of network but the load to the network is same.

The way to improve ABAC network is changing service rate from 10 to 100Mmb/s. But if you changing all paths in network it will use a lot of budget. So it is better if you change only some path that there are a lot of user such as Computer center to 100 Mb/s. But there is the limitation of network that is now connect to the maximum bit rate to the network outside so this problem can solve by adding the new connection to network outside.

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