EXPERIMENTAL ANALYSIS OF PASSIVE BANDWIDTH ESTIMATION TOOL FOR MULTIPLE HOP WIRELESS NETWORKS

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ABSTRACT

The crucial problem in the wireless network mesh was the available bandwidth. Available bandwidth is the highest throughput that the path can provide to certain consideration. There two techniques used to measure the available bandwidths which were passive and active measurement. Passive measurement allowed the network to be measure without alters the network traffic. This research will represent an experimental analysis of available bandwidth by using passive bandwidth estimation tool. The passive bandwidth estimation tools that were used were Pathload, Pathrate and Wbest. The objective of the research was to measure the available bandwidth using passive bandwidth estimation tool, compare the selected tools based on their estimation preference and to recommend the best bandwidth estimation tools. This was determined with the three factors which were the failure pattern, accuracy and consistency of the tools. The experimental analysis was done in two scenarios which were in the optimum network and network with traffic. For each scenario, the testing then was done in three different environments, one router, two routers with same bandwidth and two routers with higher bandwidth at the bridging. Laptop was placed between an access points. Twenty reading for each tool then was recorded. At the end of the experiment, the data then was analyzed to determine the result based on the objective of the experiment. Based on the result, Pathrate was the best tools to be used for both environment followed by Pathload and Wbest.

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ABSTRAK

Masalah penting dalam jaringan rangkaian wayarles adalah masalah jalur lebar. Jalur lebar adalah jumlah data yang boleh dihantar dalam jumlah yang tetap tersedia. 'Available bandwidth' adalah jumlah kapasiti jalur lebar yang tidak digunakan. Terdapat dua teknik yang digunakan untuk mengukur lebar jalur yang sedia ada iaitu pasif dan aktif. Ukuran pasif membenarkan rangkaian untuk diukur tanpa mengubah trafik rangkaian. Kajian ini akan mewakili eksperimen jalur lebar sedia ada dengan menggunakan alat anggaran pasif. Alatan yang digunakan dalam eksperimen ini adalah Pathload,Wbest dan juga Pathrate. Objektif kajian ini adalah untuk mengukur 'available bandwidth' dengan menggunakan alat anggaran pasif, membandingkan alat-alat yang dipilih berdasarkan keutamaan anggaran mereka dan mencadangkan alat anggaran yang terbaik.Tiga faktor menjadi kayu pengukur bagi analysis ini iaitu corak kegagalan, ketepatan dan ketekalan alat. Analisis eksperimen telah dilakukan dalam dua senario iaitu 'optimum network' dan juga 'network with traffic'. Bagi setiap senario, ujian dilakukan dalam tiga persekitaran yang berbeza iaitu dengan menggunakan satu router, dua router dengan lebar jalur yang sama dan dua router dengan lebar jalur yang lebih tinggi pada penyambung. Komputer riba diletakkan di antara pusat akses. Dua puluh bacaan untuk setiap alat kemudian direkodkan. Berdasarkan keputusan ketepatan,corak kegagalan dan juga ketekalan alat, Pathrate adalah alat yang terbaik untuk digunakan bagi kedua-dua situasi diikuti oleh Pathload dan Wbest.

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CHAPTER 1

INTRODUCTION.

1.0 Introduction

Wireless mesh networks has been widely used nowadays in most types of environment. It has been used in education, cities and municipalities, isolated location, hospitality and others. In healthcare part, many hospitals used wireless network. It is crucial for the doctor and the caregivers to maintain and update their patient information. The hospitals are spread out through a cluster of densely constructed building. Therefore, wireless network mesh nodes can be used around where it can send signals easily.

It can be easily, effectively and wirelessly connect entire cities using existing technology. Different from the traditional network, wireless mesh network connection is spread out among hundreds of wireless mesh nodes that communicate with each other to share the network connection across a large area.

Only one node needs to be physically wired to a network connection like internet modem. The wired node then shares its Internet connection wirelessly with all other nodes in the specific network environment. Those nodes are the node that shares the connection wirelessly with the node closest to them. The more nodes, the further the connection spreads. In other words, wireless mesh networks making the network adaptable and expandable as more or less coverage is needed.

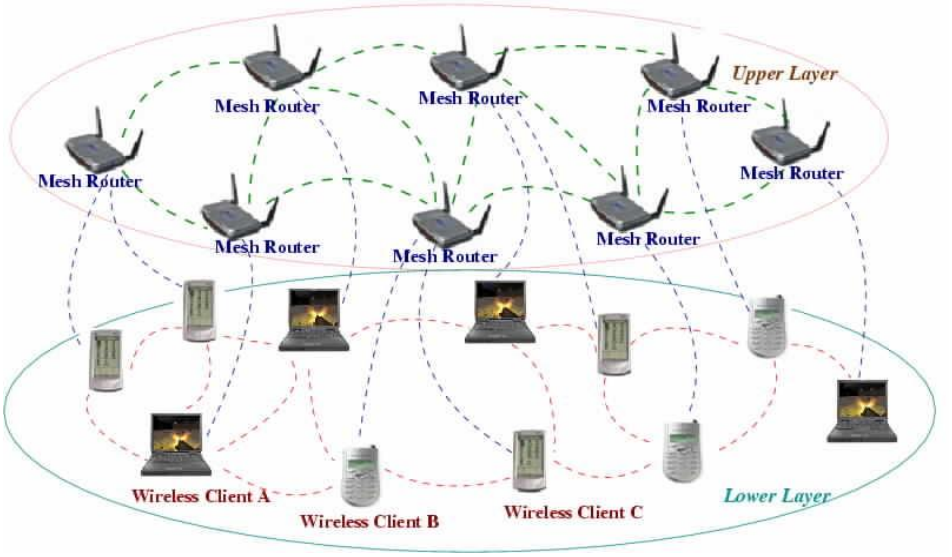

Figure 1 Example of wireless mesh network [1]

Bandwidth is referring to the amount of data that can be transmitted from one point to another point in specific given time. It is expressed in bits per second or multiples of it is as a bit/s, Kbit/ s and etc. For example, a modem with a bandwidth of 56 kilobits per second (Kbps) can transmit a maximum of about 56,000 bits of digital data in one second. By having a lot of bandwidth is very important depending on the user requirement. As an example, the university has an internet connection for all its students, surfing the internet would be very productive. It will take up a long time to load. Sometimes we need to wait to play streaming video.

Available bandwidth is a maximum throughput that the path can provide and can achieve in the presence of cross traffic [2]. It is important as much business relies on it. The increase uses of technology nowadays, may affect the Quality of Service (QoS). Therefore, it is very important to know how to determine and measure the available bandwidth. It gives information of application on how to control the traffic.

Figure 2 the available bandwidth [3].

There are two types of bandwidth estimation tools which are active measurement and the passive measurement. Passive measurement is performed by observing the traffic without intruding the network. Active measurement on the other hand, will probe the network by generating packet traffic into the network to perform the measurement. In order to be able to measure or determine the available bandwidth actively, a bandwidth estimation tool needs to be used to perform the task. However, there are multiple bandwidth estimation tools that are available that could be used. Different type of estimation tools gives a different type of reading.

1.1 Problem statement

According to the Internet World Stats, there are 2,267,233,742 of internet users [4].With the rapid growth of wireless application and the complexity of wireless network, measuring the available bandwidth has been challenging. Therefore, bandwidth estimation tools will be used to study and analyzing the bandwidth performance in the different type of wireless mesh network scenarios. There are many types of bandwidth estimation tools nowadays, but among of it which is the most suitable for the different type of scenarios. The experiment will be conducted based on the following criteria:

i. **Consistency.** The consistency of the measurement of the tool as whether it will fluctuate of overestimating or underestimating value.
ii. **Accuracy**. The accuracy of the tool will be measured to estimate the available bandwidth whether it will overestimate or not under estimate.
iii. **Failure patterns**. It will monitor and measure the reliability of the tool's failure to estimate the bandwidth throughout the testing cycle.

1.2 Objectives

This research was conducted to meet three objectives. The objectives of the research were:

i. To measure available bandwidth with selected passive bandwidth estimation tool in a multiple network environment.
ii. To compare the selected tool based on their estimation preference in a multiple network environments.
iii. To recommend the best bandwidth estimation tools in the given scenario.

1.3 Scope

In this study we will focus on analyzing the passive bandwidth estimation tool for multiple hop wireless mesh network based on several limitations:

i. IEEE 802.11 g was used as a wireless network standard.
ii. The Linux operating system was used.
iii. Three bandwidth estimation tools will be used. The tools were Pathrate, Wbest, and Pathload.
iv. Wireless hardware: Two laptops were used and also the two wireless access points (AP).
v. A measurement was tested based on the traffic generated by the bandwidth estimation tools.
vi. Twenty readings for each tool was recorded

1.4 Thesis Organization.

The research consists of five chapters:

Chapter 1 provides the overall overview of the thesis. Here, the problem statement will be introduced. Based on the problem statement, the objective of the research is being defined. Lastly, chapter one also will explain about the research scope.

Chapter 2 introduces the hardware and software that will be used in this research project. It is mainly focused on the performance of the bandwidth estimation tools. The literature review is organized in a way that readers can understand this.

Chapter 3 explains the methodology that will be used to carry out this research. The detail will be elaborated step by step process that is being used to complete the research.

Chapters 4 models will be developed in order to perform the test. It then followed by the continuously design on data analysis.

Chapter 5 all the data recorded will be analyzed in this chapter. Each reading from each tool will be analyzed based on the objectives of this research. In this chapter also, all data will be discussed further.

Chapter 6 concludes all the chapters and the recommendations for future researchers

CHAPTER 2

LITERATURE REVIEW

2.0 WLAN 802.11g

According to Wikipedia wireless local area network (WLAN) 802.11 g is the set of standard implementing on a wireless local area network. This technology has become the most reliable technology based on the bandwidth needs. The growth of the WLAN market evolved to meet the fundamental needs of business and consumers.

802.11g is one of the standards used for high speed wireless networks, commonly known as Wi-Fi. This standard was created by the IEEE (Institute of Electrical and Electronics Engineers) in June of 2003 and uses a 2.4 to 2.5 gigahertz radio frequency to send and receive data from one device to another [5]. 802.11g support multiple data rates that allow the client to communicate at the best possible speed [6].

2.1 Available bandwidths

Available bandwidth is a term used to define the maximum throughput that flow between two hosts can achieve in the presence of cross-traffic. It is useful for the route selection in overlapping networks, traffic engineering and Quality of service (QoS) verification. The available bandwidth (ABW) at a link is its unused capacity. Based on PAESSLER there were two problems when measuring the available bandwidth. The two problems are:

1. The only way to measure available bandwidth is to create as much as uploads as it can handle while measuring the data rate.
2. For an exact measurement, two laptops that are placed directly on both ends of the data line.

2.2 Bridging technologies.

According to *Wikipedia* it is illustrated as the action taken by network equipment to allow two or more network communication, segment creating a collective network [7]. It is also does not carry out compiles processes on the data frame and forwarding to the next link in the direction target. There are four types of network bridging technologies which are simple bridging, multiport bridge, learning or transparent bridging and source-route bridging [8].

2.3 Bandwidth estimation tools.

Many techniques have been developed to estimate the available bandwidth [9]. There are two types of mode to measure available bandwidth estimation tool being introduced that are passive mode and also an active mode [10]. But in this experiment we only used passive mode. Passive mode means we captured packet without injecting any extra traffic to the network. We analyze the traffic without intruding it. There are a few examples of bandwidth estimation tools that have been widely used in most existing experiments like Pathload, Pchar, Pathchar, and others [11].

2.3.1 Pathload.

Pathload is a tool that is used to estimate the available bandwidth of end-to-end host from a host sender to receiver [14]. Pathload consist of a process running as a sender and a process running at receiver. Available bandwidth is the maximum throughput that a flow can get on the path between sender and receiver without reducing the rate of the traffic

```
Line # | Actual output
~~~~~~~~~~~~~~~~~~~~
Line 1 : jawks [507]$ ./pathload_rcv -s sirius
Line 2 : Receiver jawks starts measurements on sender sirius at Sun Apr 6 15:29:44 2003
Line 3 : Receiving Fleet 0, Rate 97.40Mbps
Line 4 : Receiving Fleet 1, Rate 193.55Mbps
Line 5 : Receiving Fleet 2, Rate 145.47Mbps
Line 6 : Receiving Fleet 3, Rate 121.44Mbps
Line 7 : Receiving Fleet 4, Rate 109.42Mbps
Line 8 : Receiving Fleet 5, Rate 103.41Mbps
Line 10:        *****  RESULT *****
Line 11: Available bandwidth range : 97.40 - 103.41 (Mbps)
Line 12: Measurements finished at Sun Apr  6 15:29:44 2003
Line 13: Measurement latency is 5.69 sec
```

Figure 3 shows the example reading of Pathload.

2.3.2 Pathrate.

Pathrate is an end-to end estimation tools. It requires the user to have an access at both ends of the path. It can be run from user-space, and does not require super user privileges. It also consists of two types of files Pathrate_snd (run on the sender) and Pathrate_rcv (run at the receiver).

```
./pathrate_rcv -s altair -v -o test.out
  pathrate run from altair to jawks on Wed Apr  9 18:07:11 2003
  --> Average round-trip time: 0.3ms

--> Minimum acceptable packet pair dispersion: 15 usec

-- Maximum train length discovery --
        Train length: 2 ->       98 Mbps
        Train length: 3 ->       65 Mbps
        Train length: 4 ->       98 Mbps
        Train length: 5 ->       98 Mbps
        Train length: 6 ->       98 Mbps
.............................................................
.............................................................
        Train length: 36 ->      98 Mbps
        Train length: 40 ->      94 Mbps
        Train length: 44 ->      97 Mbps
        Train length: 48 ->      98 Mbps
        --> Maximum train length: 48 packets
```

Figure 4 shows the example of sample output of Pathrate.

2.3.3 Wbest.

Wbest is a wireless bandwidth estimation tool that is designed for application that requires the fast convergence time and low intrusiveness [15]. It provides the capacity and available bandwidth information of the underlying wireless networks. It works by estimating the effective capacity of the wireless network. Then, the format determines the achievable throughput and infers the available bandwidth. It developed and used in Linux [16].

It is two stage algorithm where the first stage the packet pair techniques is estimated by the success capacity over a flow path where the last hop is a wireless LAN (WLAN) and followed by the second stage where the packet pair technique is determined by the reachable throughput to conclude the available bandwidth[17]. One of the advantages of the Wbest is by statically detecting the available fraction of effective capacity to ease estimation delay and the impairing with the random wireless channel errors.

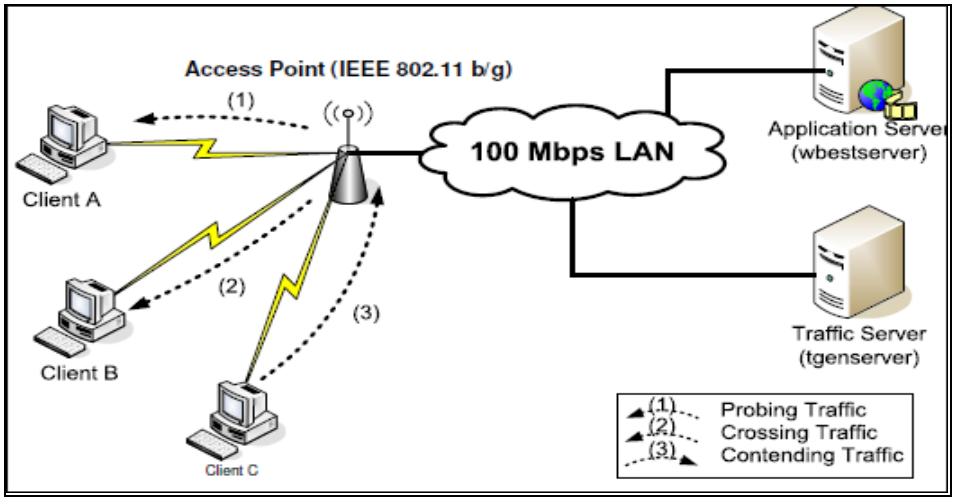

Figure 5 shows the example of Wbest implementation.

The Wbest has two executable files which are Wbest_snd and Wbest_rcv. Each of it needs to be run on two end hosts of the network path. It then will measure the network path from the sender to the receiver. The Wbest estimation must be started on the receiver first followed by the sender port. The Wbest output wills report both effective capacity and the available bandwidth on the sender site.

```
On the Sender:
------------------------------------------------------------
> ./wbest_snd -h wbest
hostname: wbest
Looking up TCP server wbest...
TCP connected to wbest:9878
Looking up UDP wbest...
UDP connected to wbest:1234
The timer resolution is 1000 usecs.
The gettimeofday resolution is 0 usecs.
Ce = 30.185917
PacketTrain: sending 30 PT with 386.935404 us per packet, at 30.185917 Mbps
Real sending rate: 30.180879 Mbps, time spend: 11610.000000 us, average packet time 387.000000 us
Ab = 24.125469
Total estimation time: 416001 usec.
WBest sender is now off
------------------------------------------------------------
```

Figure 6 shows the example of Wbest output

2.4 Existing research

In order to require information regarding to the performance of the passive bandwidth estimation tools in a wireless mesh network environment few journals, articles, books, and research studies has been studied and analyzed. The journals reviewed have some comparison to our research topic. Below are some journals and research studies that are correlated to our research topic.

2.4.1 Experimental Comparison of Bandwidth Estimation tools for Wireless Mesh Networks.

In this paper, the researcher has performed an experimental analysis of bandwidth estimation tools. The objective of this is to examine the performance of the tools and to evaluate the existing tools. They examine the performance of four-probe based and one passive bandwidth estimation tool. They also performed an analysis of the various types of parameters such as number of hops, rate-adaptation, interference and their result on estimating the available bandwidth in WMNs. The evaluation of different test bed was performing. Based on the result, they suggest that the probe-based tools are not the best choice for the wireless networks.

2.4.2 Evaluation and Characterization of Available Bandwidth Probing Techniques.

In this paper, they proposed a simple gap model that seizes how competing traffic on a network link affect the gap value in packet pairs and packet trains. Two design techniques were also proposed in this paper to estimate the available bandwidth using IGI algorithm and PTR. They use a simulation to study the dynamic on the multiple networks. Based on the result, it shows that the IGI algorithm method loses accuracy if the tight link is does not have bottleneck link. Therefore, in this paper they suggest that PTR method is the ideal method of estimating the available bandwidth.

2.4.3 Study and analysis of bandwidth flow estimation technology for wired /wireless network.

In this paper, the researcher accesses the complexity through bandwidth control application. They also used the existing technique for the bandwidth estimation. They do the comparison between existing tools and technique. Different scenario and test-bed configuration has been performed. The result of the software programmed Spruce, IGI, PTR, Abing, Pathload, Yaz and Pathchip are examined in term of accuracy, and time.

2.5 Comparison of the existing research

Journal	Experimental Comparison of Bandwidth Estimation tools for Wireless Mesh Networks	Evaluation and Characterization of Available Bandwidth Probing Techniques
Tools	They used four types of probe-based and one passive tool. The four probes-based are Spruce, Pathload, pathChrip and PTR.	They used Spruce, ProbeGap, IdleGap, and Pathload.
Wlan environment	They perform an experiment on outdoor test bed. 1. **1st test bed** – controlled laboratory environment. 2. **2nd test bed**-wildlife environment where they use 20 nodes that spread over 2000 acres of forest land.	They perform the test in various forms of scenario. They perform the test on unified, flexible and low cost platform.
Simulation Mode	They perform an analysis experiment to evaluate the performance of bandwidth estimation tool using default parameter in a wireless setting, various parameters and different types of environment	The compared the tools based on the proposed time.
Measuring Method	They collect the data on: 1. The AV- B/W for single hop with interfering traffic. 2. The AV-B/W for single hop with rate-adaptation. 3. The performance of the passive scheme on outdoor test bed for single hop with interference	They perform a comparison between each tool. The tools are spruce,Pathload,yaz,IGR/PTR,Assolo,Abing,pathchrip, and also DieTOPP

Journal	Study and analysis of bandwidth flow estimation technology for wired /wireless network	Experimental Analysis of Passive Bandwidth Estimation tool for Multiple Hop Wireless Network
Tools	They used IGI and PTR.	In this experiment, the passive tools will be used. The passive tools are Pathload, Pathrate and Wbest
Wlan environment	They perform the test in different form of environment.	The test will be conducted in two types of different environments. The two types of environment are optimum network and network with traffic. The scenarios are 1. One access point is used to measure the tools consistency. 2. Two access points are used to measure the tools consistency. 3. Access point to where the bridging is higher than the PC
Simulation Mode	They analyzed the performance of the tools based on different environment and criteria.	The analysis will be tested in term of accuracy, consistency and also failure patterns. Different test bed will be designed in the experiment.
Measuring Method	They collect the data based on : 1. Performance of IGI, PTR and Pathload based on accurate measurement. 2. How the probing size and the packet size affect the measurement accuracy. 3. Study the performance of the IGI and PTR on a network path.	The data will be collected based on 1. Accuracy 2. Consistency 3. Failure patterns. Different test bed environment

Table 1.0 Comparison between the journals

CHAPTER 3

METHODOLOGY

3.0 Introduction

The project will be done by performing an analysis experimental on available bandwidth for multiple hop wireless mesh network using passive bandwidth estimation tools. The analysis will be based on three different criteria such as accuracy, consistency and the failure pattern of the bandwidth estimation tool. For each criteria's, 20 test results will be collected.

To make sure the objective of the research is fulfilled; a few steps have been identified as a guideline. The guideline is:

1. **Information gathering**. Collect all data from all resources based on the research topic.
2. **Planning and identifying hardware and software tools**. All the hardware and software tool must be determined to make sure it is compatible with the test bed
3. **Hardware setup, software configuration and experiment design**. It is to ensure that the experiment can be performed.
4. **Implementation and experimentation**. Performing the testing based on the predefine model is used to collect all the data related to the experiment.
5. **Data analysis**. All the data are gathering to be analyzed.

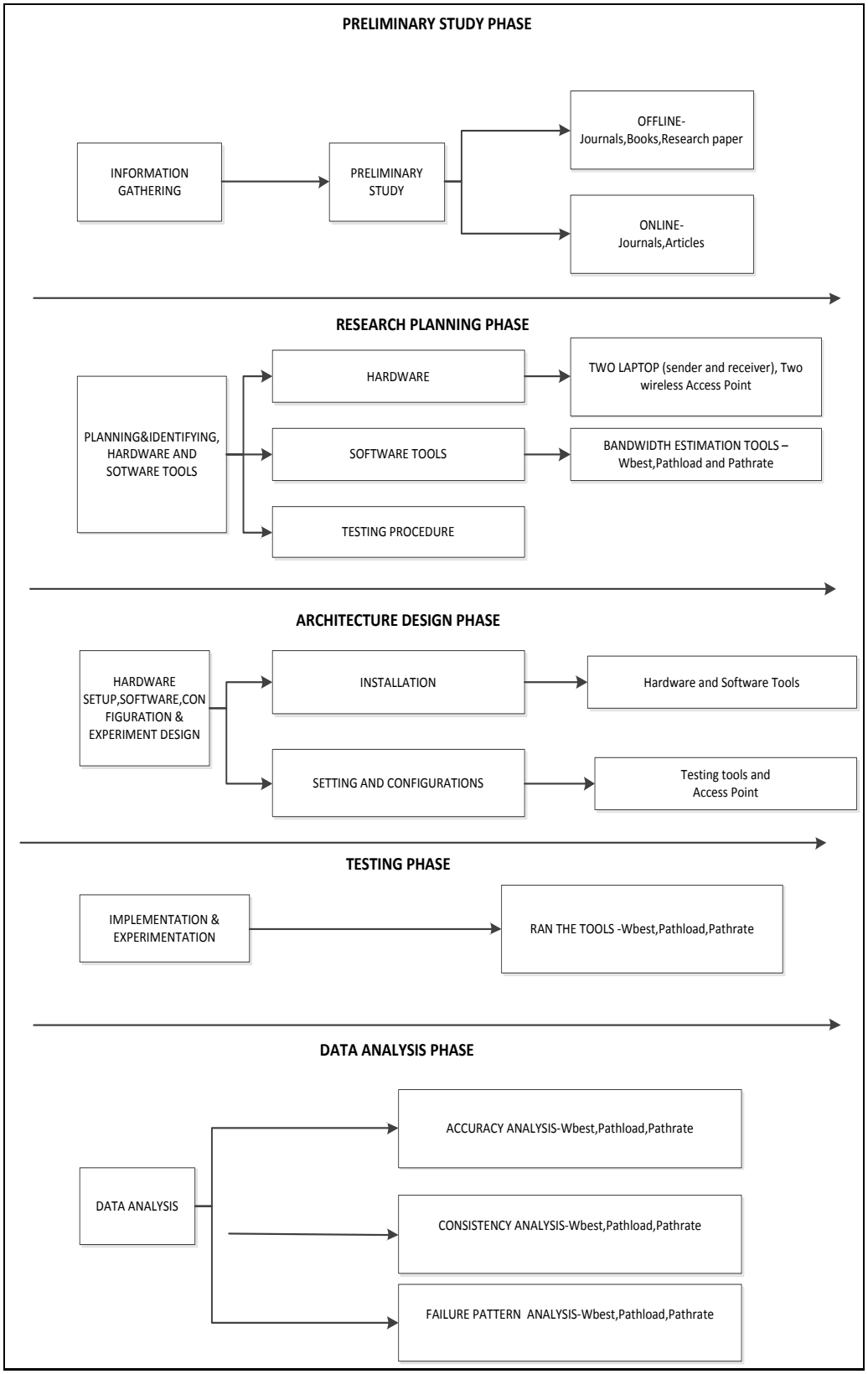

Figure 7 shows the guideline for this experiment.

3.1 Methodology.

To make sure this research can be performed smoothly, five phases were defined to be used. This methodology helps in collecting more accurate data. The research will be performed phase by phase accordingly. The phases were:

1. Preliminary study phase
2. Research planning phase
3. Architecture design phase
4. Testing phase
5. Data analysis phase.

3.1.1 Preliminary Study Phase

The first step before was by doing a preliminary study on the research topic. This was to ensure that the research project will be in the right path. In addition, the problem statement became a guideline in planning and extracting the right information. Various sources were used to gather all information from the offline - base resource to the online-based resource. The best recommendations, bandwidth estimation tools, techniques and different type of environment related to this project was taken into consideration. The existing research also was used in order to know more about the research topic.

3.1.2 Research Planning Phase

The second step was the research planning phase. In this phase all the hardware and software tools were determined for experimental setup. The testing procedure than was used to make sure all of its work. The required hardware and bandwidth estimation tools were crucial for the research project to be carried out. Two laptops were needed, one act as a sender of the packet and another one act as the receiver. Wireless access point (AP) also required in this research to act as a bridge to connect the two laptops. At the end, the testing step and procedure need was defined so that the objectives of this research will be accomplished. Scope limitation also is defined during this phase.

3.1.3 Architectural Design Phase

In this phase the installation and the configuration setting of the hardware and the bandwidth estimation tools software is executed to provide the test bed for the wireless environment to perform the testing of the bandwidth estimation tool in order to obtain the data readings for the analysis phase. These activities involve:

I. **Two laptops were set up, one for the sender and one for receiving**. Each of the laptop will be installed with the bandwidth estimation tools. The bandwidth estimation tools are Wbest, Pathrate, and Pathload.
II. **Wireless access point (AP)** – set up the wireless AP with the default setting for the wireless communication to take place between the sender and the receiver. In this phase, two wireless access points will be used.

III. **Optimum network (Network without external traffic) and Network with traffic** – the experiment was done in two types of environments for each tool to get the result. Each tool was run for twenty cycles.

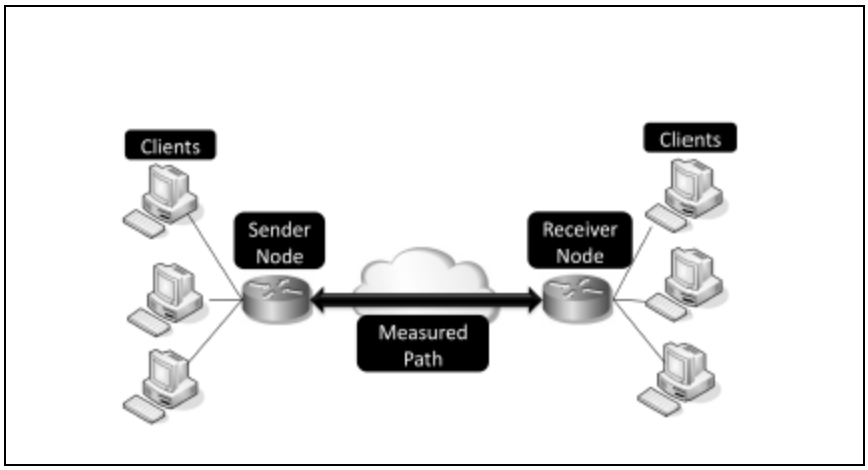

Figure 8 shows the basic architecture design.

3.1.4 Testing Phase

After the design has been complete, the data collection will be done. The selected tool will be tested to obtain the measurement of the bandwidth as the data to be analyzed. 20 readings will be taken for each experiment based on it criteria such as accuracy, failure pattern and consistency. Each experiment will be performed on different types of environment.

1. One Access Point scenario.
2. Two Access Point scenarios with same bandwidth rate
3. Two Access Point scenarios where the bridging has higher bandwidth rate.

3.1.5 Data Analysis Phase

In this phase, the entire data gather will be analyzed. All the reading for each experiment will be taken to answer the research objective and problem statements. The conclusion of this project will be derived from the data analysis. Here they will be a table of measurement.

WBest	1	2	3	4	5	6	7	8	9	10
Av-Bw										
WBest	11	12	13	14	15	16	17	18	19	20
Av-Bw										

Table 2.0 the example of a data analysis table.

3.2 Hardware and Software

The experimental setup is made to provide a wireless local area network 802.11g standard platform for both to communicate where one of them will be sent and one of it will act as receiver to estimate available bandwidth. Based on the design phase it is important to ensure hardware and software tools used to perform and carry out the experiment to obtain the data

Hardware used:

1. Laptop

The Laptop will be installed with the Linux based operating system such as fedora. Most of the passive estimation tool only can work on the open source software. The estimation tools such as Pathload, Pathrate and Wbest will be installed to measure the accuracy, consistency and failure patterns.

2. Wireless Access Point.

In this experiment two wireless access points will be used. The experiment will be done in two different environments, optimum network and network with external traffic. For each environment the number of access points used was different.

3.3 Gantt chart

It is a type of a bar chart that is used in project planning. It is a graphical representation of duration tasks against time. All the activities will be drawn into the Gantt chart so that the clear project's progress can be seen. It illustrates the start and finish dates of the terminal and summary project elements. The duration of the final year project (FYP 1) is about 14 weeks while the duration of the final year project (FYP 2) is about 20 weeks. Therefore, a consistent schedule is needed to make sure the research can be done according to dateline. It is important to ensure all activities are completed before the dateline.

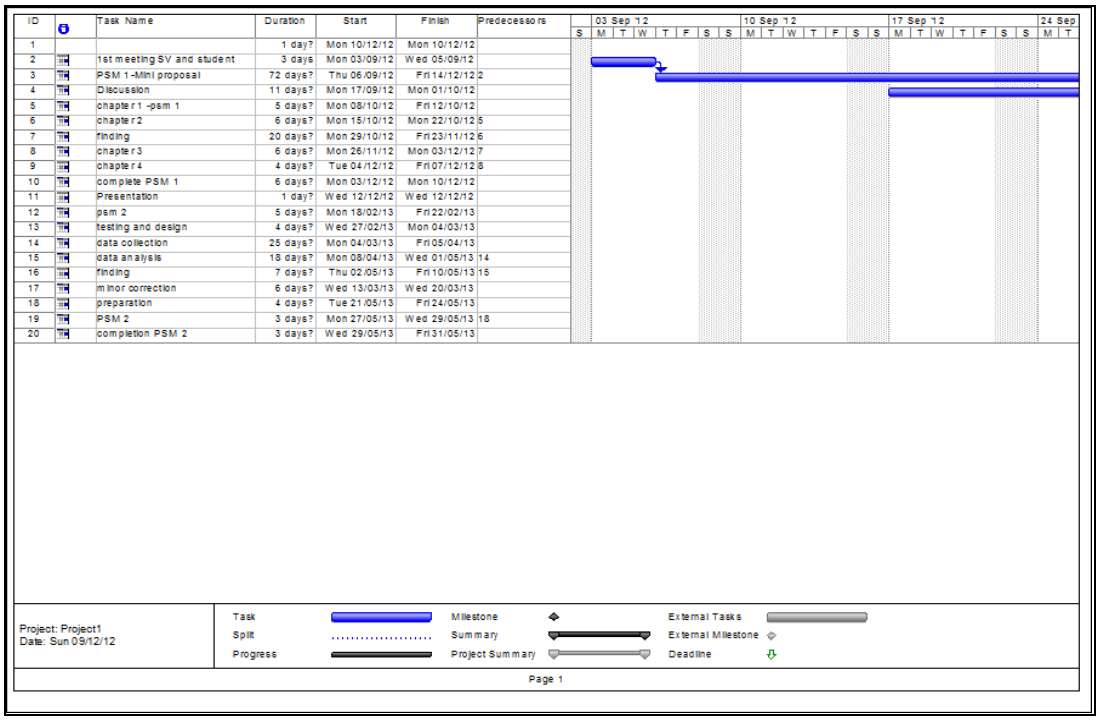

Figure 9 Gantt chart for final year project 1 (PSM1)

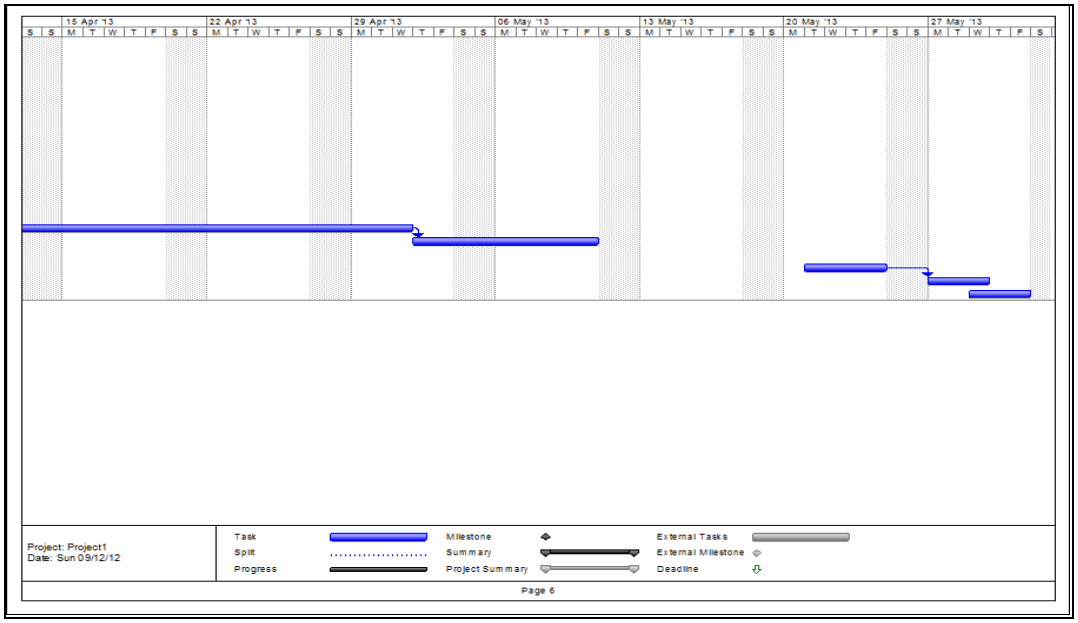

Figure 10 Gantt chart for final year project 2 (PSM2)

CHAPTER 4

DESIGN AND IMPLEMENTATION

4.0 Introduction.

In this chapter the design of the experimental analysis and the implementation of the tools was being discussed. In this experimental analysis the design was based on the objectives of the research. This was to ensure that it fulfilled the objective requirement. For the design it must be able to measure the accuracy of the available bandwidth, the failure pattern and the consistency of the tools while measuring the available bandwidth.

The implementation was the realization of the idea. The bandwidth estimation tools need to be implemented to measure the available bandwidth. In this experimental Wireless Local Area Network (WLAN) where the two nodes will communicate with each other via a wireless access point was used. The file transport protocol was also used to get varieties of result.

4.1 Design of the experiment.

For this experimental analysis, there were two types of design. The first type of design was using one wireless access point (AP) and the second design was using two types of wireless access point (AP). In this experiment, we wiìl have two types of environment setup. The open optimum network and network with external traffic.

1. **Optimum Network (without external traffic).**

For the optimum network, there was no external traffic involved. Example of external traffic involved was when FTP (File Transfer Protocol) as used. In this test bed everything was fixed. The bridging between both laptop and access point (AP) also was controlled.

One wireless access point was placed between Laptop. The setup was made to provide a wireless local area network for both laptops to communicate where one of them was a sender and one was a receiver. In this figure it shows that the wireless access point was connected between each end of the hardware device. The bridging between both laptop and wireless access point was fixed.

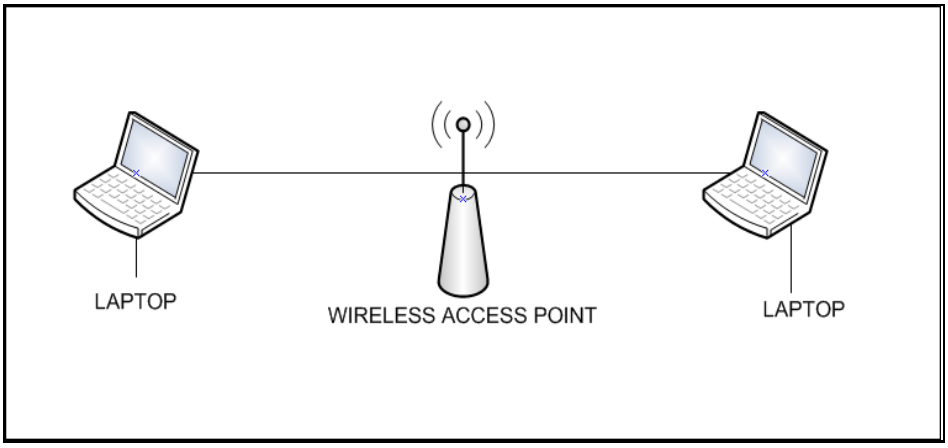

Figure 11 Design for optimum network by using one access point

Two laptops and two wireless access points were placed at each end. The bridging between laptop and wireless access point was same.

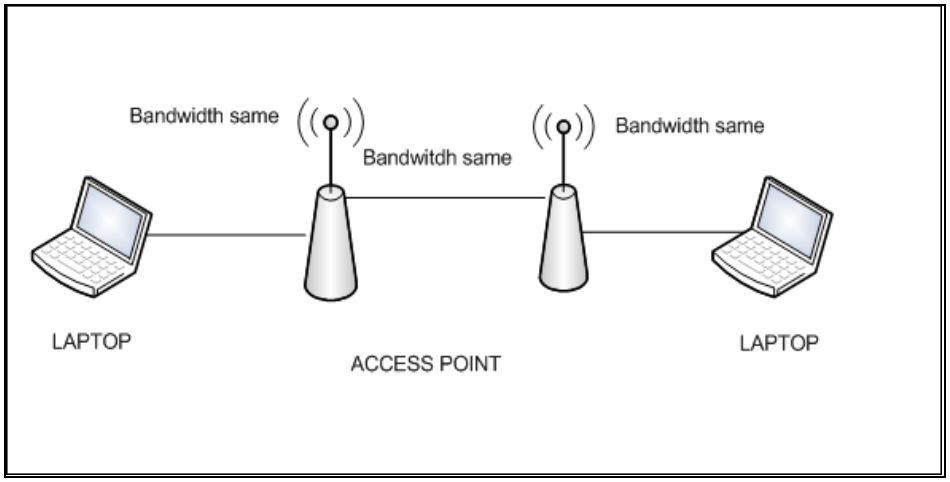

Figure 12 Design for optimum network by using two access points with the same bandwidth.

Two laptops and two wireless access points were placed at each end. The bridging between laptop and wireless access point was lower compared to the bridging between two wireless access points which was higher.

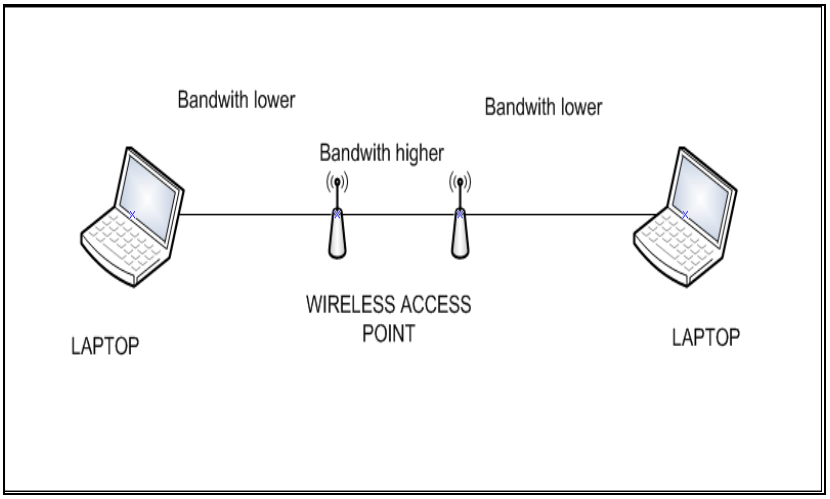

Figure 13 Design for optimum network by using two access points with different bandwidth.

2. Network with external traffic.

Network with external traffic was a situation where there was an activity involved such as file sharing by using File Transfer Protocol (FTP). In this experiment File Transfer Protocol will be used as a mark to get the data. To make the experimental analysis succeed one laptop will be the sender and the other laptop will be the receiver. Figure 14 shows the design of the experiment. One wireless access point will be placed between them.

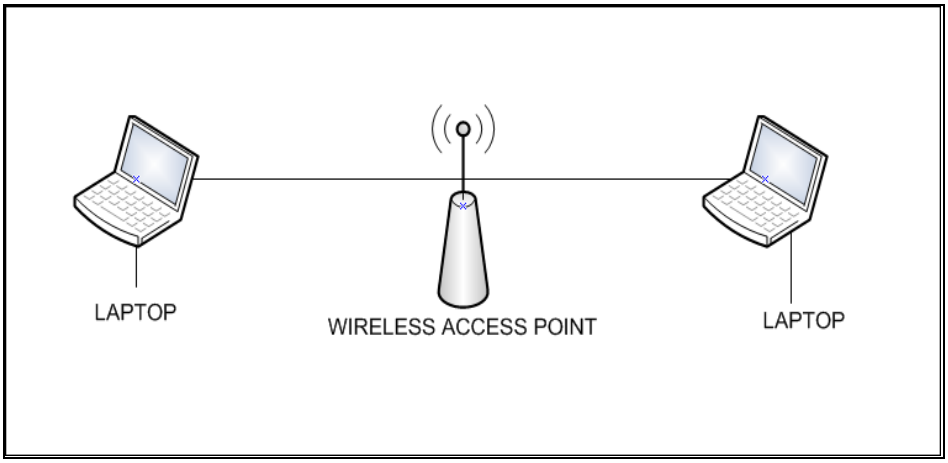

Figure 14 Design for network with external traffic using by one access point

Two laptops and two wireless access points were placed at each end. The bridging between laptop and wireless access point was same. At this time the File Transfer Protocol was used to transfer files from sender to receiver.

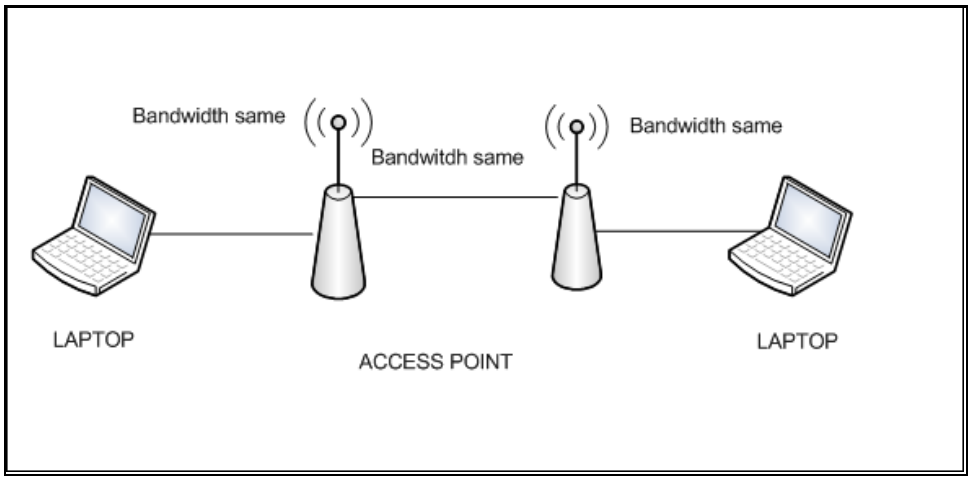

Figure 15 Design for optimum network by using two access points with the same bandwidth

Two laptops and two wireless access points were placed at each end. The bridging between laptop and wireless access point was lower compared to the bridging between two wireless access points which is higher. FTP was involved in this testing.

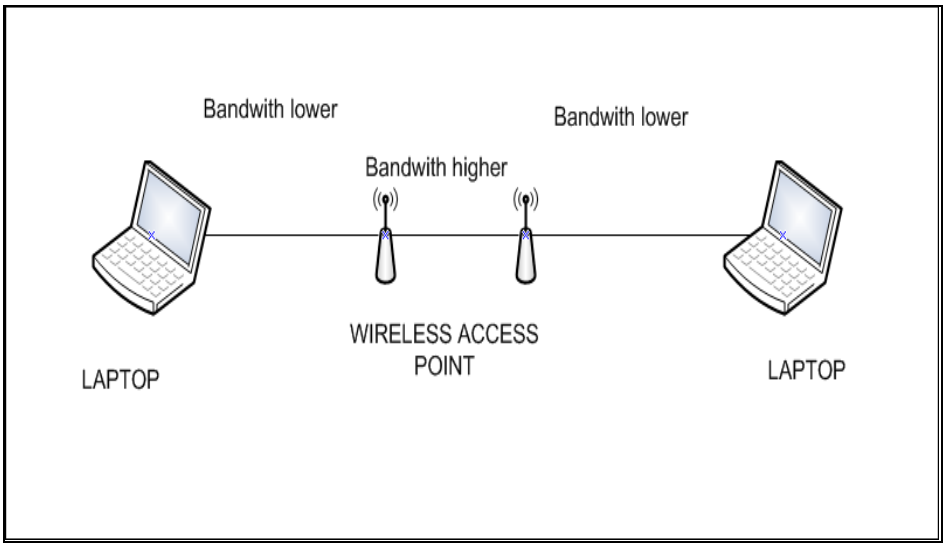

Figure 16 Design for optimum network by using two access points with different bandwidth.

4.2 Testing Plan

The testing has been done. In this experiment, twenty readings from each tool were recorded. The reading was based on the accuracy, consistency and the failure pattern of each bandwidth estimation tool. Each estimation tool will have different types of reading. The example of a table that was used in the data analysis was shown. The testing will be done in three scenarios where:

a. One wireless access point is used for both optimum network and network with traffic.

b. Two wireless access points with the same bandwidth rate consists of both optimum network and network with traffic.

c. Two wireless access points with the bridging has higher bandwidth rate consists of both optimum network and network with traffic.

.

WBest	1	2	3	4	5	6	7	8	9	10
Av-Bw										
WBest	11	12	13	14	15	16	17	18	19	20
Av-Bw										

Table 3.0 the reading of Wbest.

Pathrate	1	2	3	4	5	6	7	8	9	10
Av-Bw										
Pathrate	11	12	13	14	15	16	17	18	19	20
Av-Bw										

Table 4.0 the reading of Pathrate.

Pathload	1	2	3	4	5	6	7	8	9	10
Av-Bw										
Pathload	11	12	13	14	15	16	17	18	19	20
Av-Bw										

Table 5.0 the reading of Pathload.

CHAPTER 5

RESULT AND DISCUSSION

5.0 Introduction.

This chapter will elaborate more on the findings gathered of this project. This chapter will perform all the mechanism involved with the result refers to the accuracy of the tool, consistency of the tools and failure pattern of the tools.

5.1 Result Analysis.

For this experimental analysis, twenty cycles of testing have been done. The result of available bandwidth for each cycle was recorded in the table. Each available bandwidth was recorded in Mbps format. Pathrate, Pathload and Wbest were the tool used in this experimental analysis. The result was recorded base on the accuracy of the tool, consistency of the tool and the failure pattern if the tool

In this experiment, the accuracy of the tools will be collected by using this formula. It was used to determine the accuracy of the tool based on the benchmark that has been set. The benchmark was set based on the certain criteria such as the range of the bandwidth, signal to noise ratio (SNR) and others. By default the maximum bandwidth used was 54 Mbps [**18**]. In this experimental analysis the benchmark that will be used was from 1Mbps to 54Mbps.

The consistency of the tool was determined by calculating the mean and the standard deviation (SD) for each tool. For each tool, the value of the mean and standard deviation was different. The lowest standard deviation value determined the most consistent tool.

For the failure pattern, the result was calculated based on the percentage value. The reading that was below the benchmark or above the benchmark will be eliminated. Each tool has own characteristic to work in different environments. The benchmark that was used in this situation was 1Mbps to 54Mbps.

5.1.1 Optimum Network condition.

In this testing, the available bandwidth of each tool was recorded for twenty cycles. Different result was recorded based on the tool used.

A. One router

1. Pathrate.

In this experiment, the tool was set up and run based on the figure shown below.

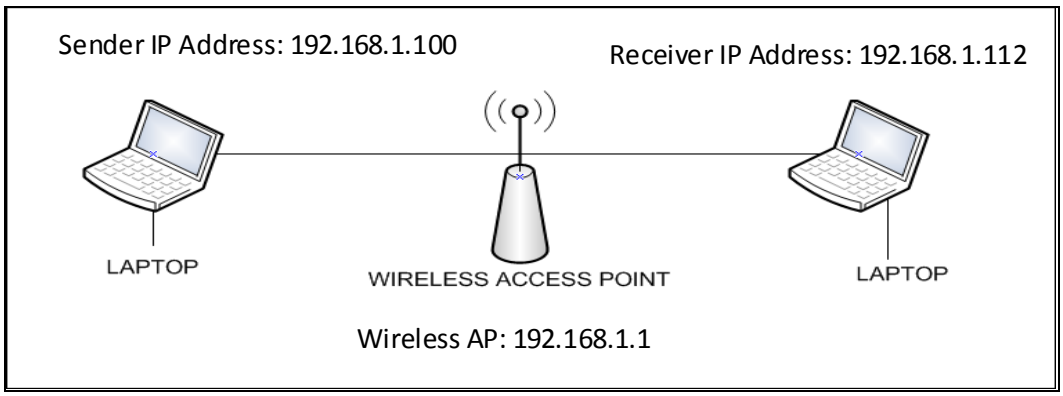

Figure 17 Design setup

Table 6 shows the reading and the result of Pathrate for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table.

Pathrate	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	8.6	9.5	9.0	8.9	9.3	8.7	8.8	9.2	9.3	8.8
Pathrate	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	9.2	9.2	9.2	9.1	9.2	9.1	9.1	9.3	9.1	8.9

Table 6 Pathrate readings

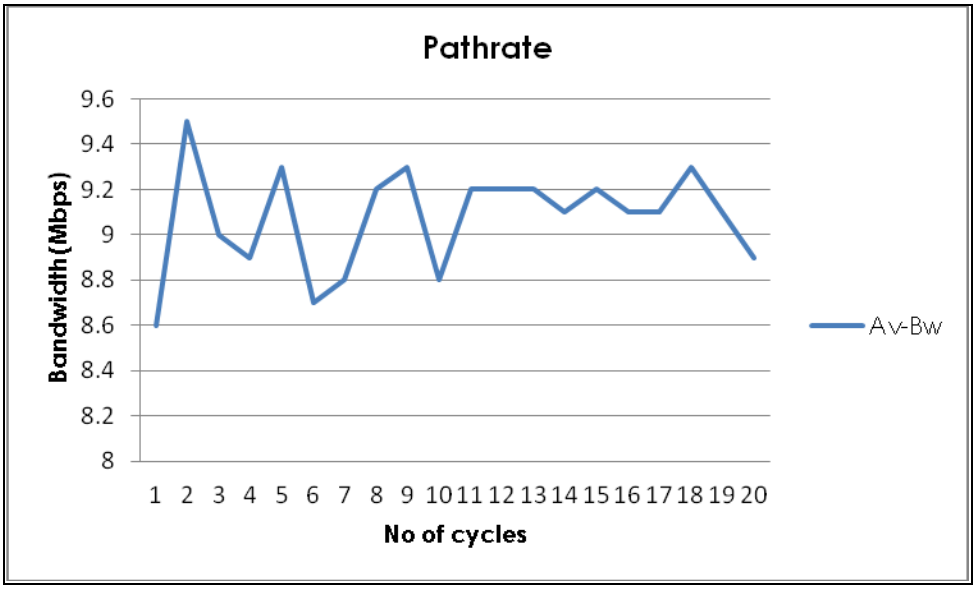

Figure 18 Pathrate graph

From the figure 18, we can see that Pathrate was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was at 2nd cycle where the reading of the Av-Bw was 9.5 Mbps and the lowest reading was at 1st cycle which is 8.6 Mbps.

In terms of failure pattern, Pathrate tools produce all results for twenty cycles. The result produce by Pathrate was between the benchmark stated that was from 1 Mbps to 54Mbps.Therefore, shows that Pathrate has 0% of failure pattern.

For the accuracy, 100% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. The lower reading or overestimated reading of the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathrate was 9.075 and the SD was 0.2291.

2. Pathload.

Table 7 shows the reading and the result of Pathload for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table.

Pathload	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	3.3	3.3	4.1	4.7	4.1	3.4	5.1	5.1	5.1	5.1
Pathload	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	5.1	4.8	4.2	3.5	4.7	4.6	5.1	4.4	5.1	3.9

Table 7 Pathload readings

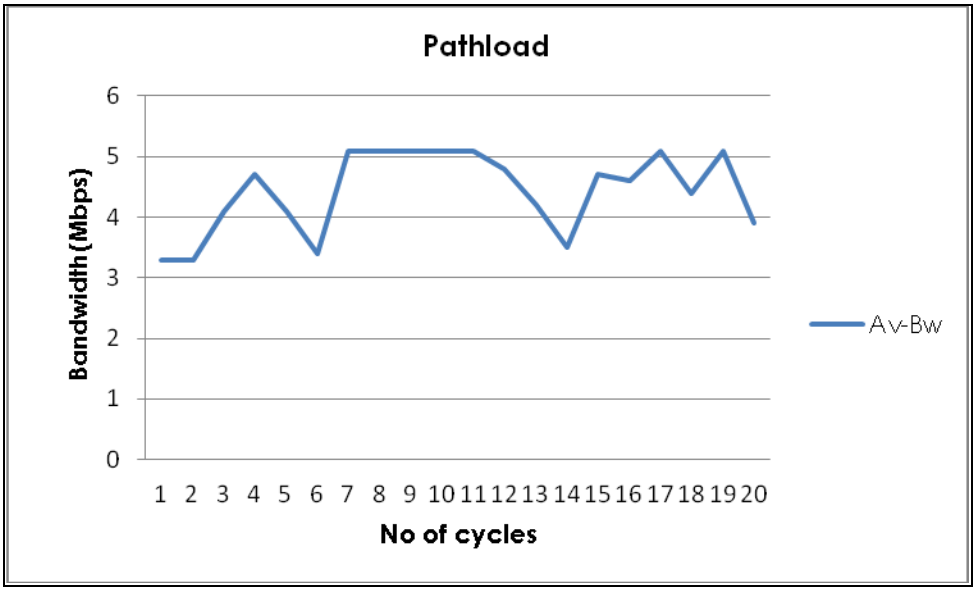

Figure 19 Pathload graph

From the figure 19, we can see that Pathload was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 5.1 Mbps and the lowest reading was 3.3 Mbps.

In terms of failure pattern, Pathload tools produce all results for twenty cycles. . The result produce by Pathload was between the benchmark stated that was from 1 Mbps to 54Mbps.Therefore, shows that Pathload has 0% of failure pattern.

For the accuracy, 100% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. The lower reading or overestimated reading of the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathrate was 4.435 and the SD was 0.6683.

3. Wbest.

The experiment was carried out using Wbest. In this experiment, the tool was set up and run based on the figure. Table 8 shows the reading and the result of Wbest for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table.

Wbest	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	2.3	5.8	2.6	4.4	4.8	3.9	2.7	-87	-16.7	-0.5
Wbest	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	-0.4	2.7	3.0	3.2	4.3	-0.03	5.9	4.8	3.8	3.3

Table 8 Wbest readings

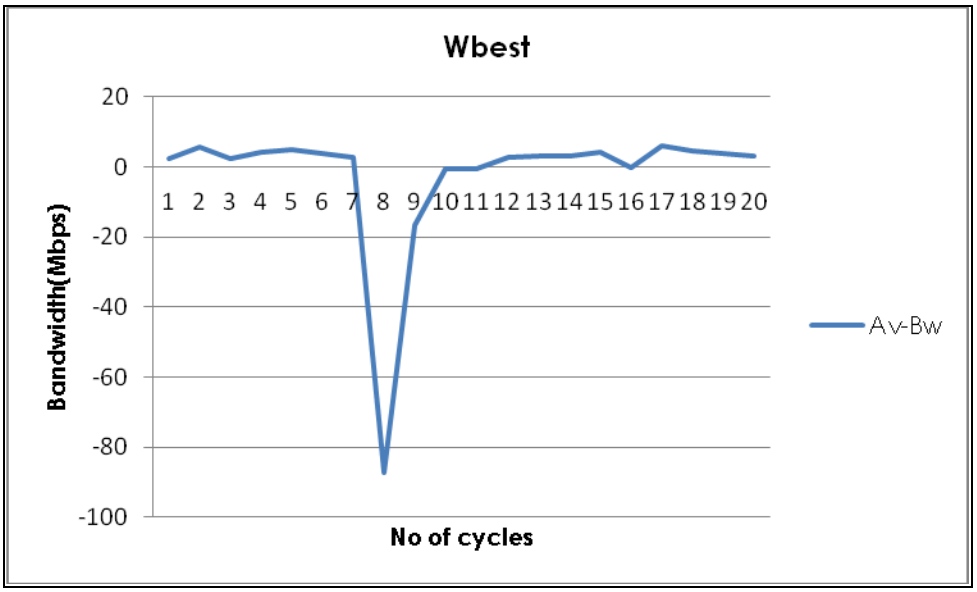

Figure 20 Wbest graph

From the graph, we can see that Wbest was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 5.97 Mbps and the lowest reading was 2.60 Mbps.

In terms of failure pattern, Wbest tools produce all results for twenty cycles. There were five readings which were not valid since it does not match the benchmark that was being stated. The benchmark that was used in this experimental analysis was between 1Mbps to 54Mbps. Therefore, it shows that Wbest has 25% of failure pattern.

For the accuracy, 75% of the estimated readings were in the range of the benchmark that has been set while 25% of the reading was below the benchmark.

For the consistency, the mean and standard deviation were calculated. The mean for the Wbest was 2.9064 and the SD was 1.9844.

B. Two routers with the same bandwidth

In this experiment, the tool was set up and run based on the figure shown below

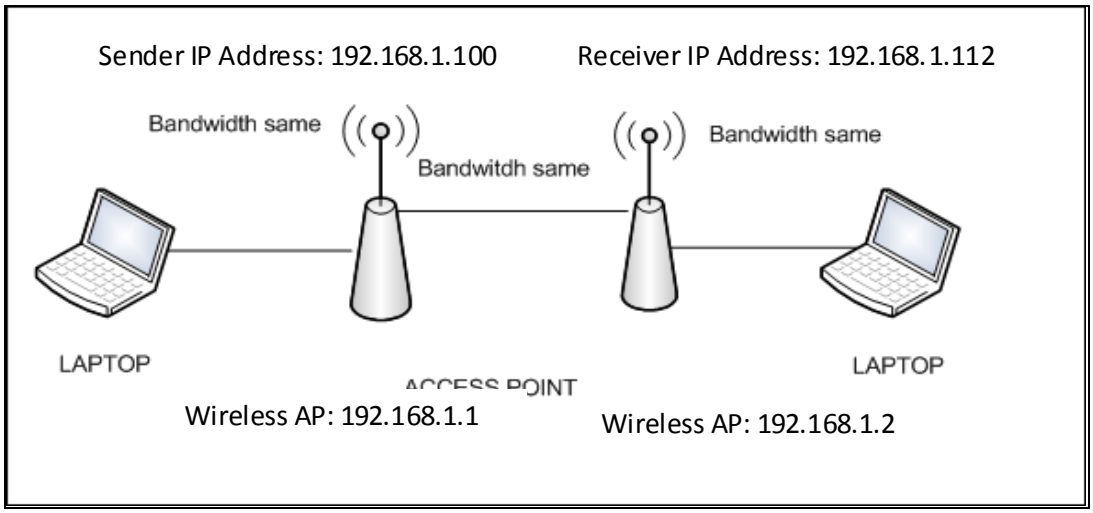

Figure 21 Design setup

1. Pathrate

Table 9 shows the reading and the result of Pathrate for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table.

Pathrate	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	5.3	6.3	6.4	6.1	5.7	6.3	5.6	6.2	5.9	7.4
Pathrate	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	5.7	5.9	6.7	6.3	5.9	6.2	5.2	6.3	6.8	6.5

Table 9 Pathrate readings

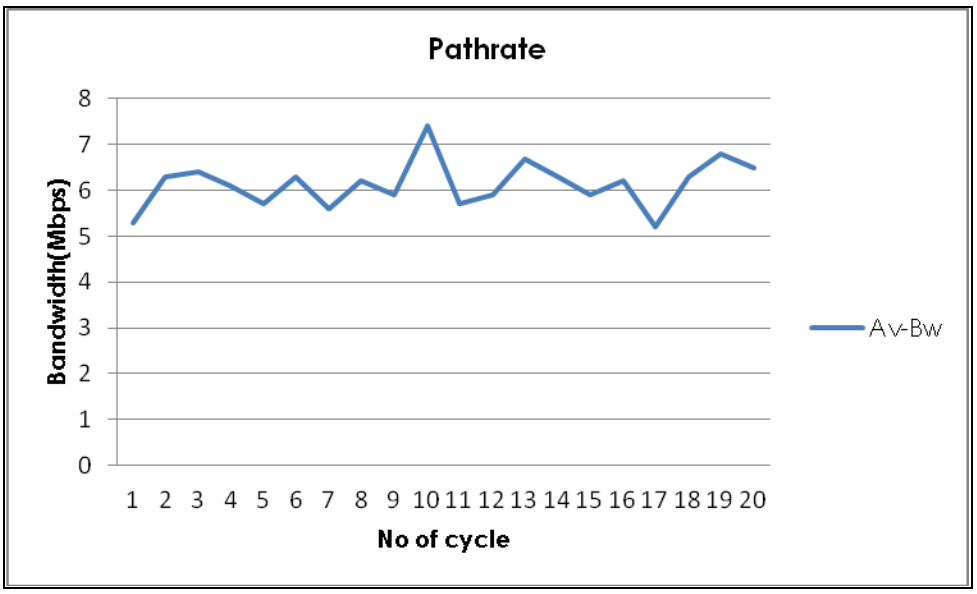

Figure 22 Pathrate graph

From the figure 22, we can see that Pathrate was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 7.4 Mbps and the lowest reading was 5.2 Mbps.

In terms of failure pattern, Pathrate tools produce all results for twenty cycles. . The result produce by Pathrate was between the benchmark stated that was from 1 Mbps to 54Mbps.Therefore, shows that Pathrate has 0% of failure pattern.

For the accuracy, 100% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. The lower reading or over the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathrate was 6.135 and the SD was 0.5173.

2. Pathload.

Table 10 shows the reading and the result of Pathload for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table.

Pathload	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	3.5	1.7	0.8	2.0	2.3	2.0	0.3	1.3	1.7	1.9
Pathload	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	2.4	2.3	2.1	1.8	2.1	1.7	2.1	1.6	1.1	1.4

Table 10 Pathload readings

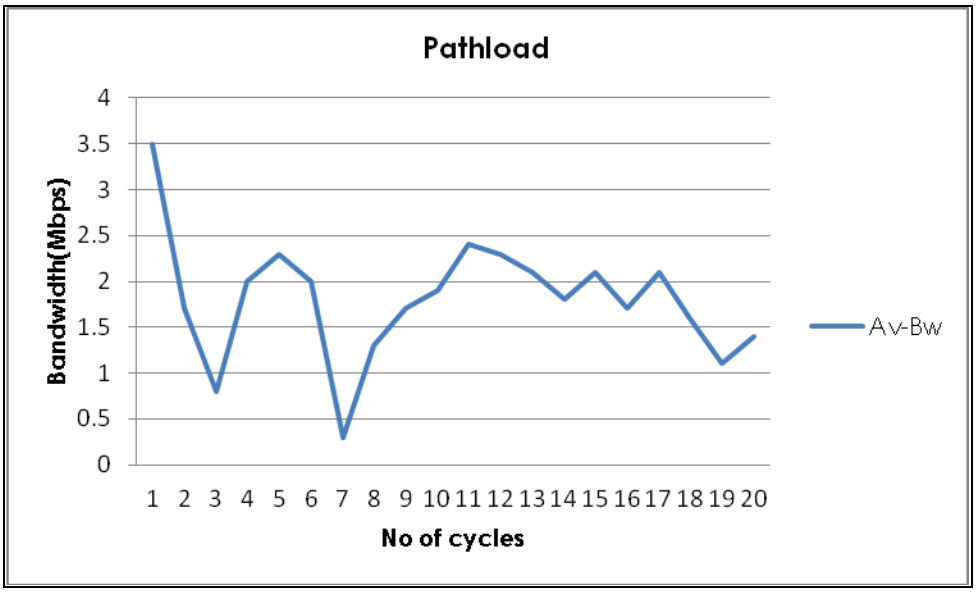

Figure 23 Pathload graph

From the figure 23, we can see that Pathload was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 3.5 Mbps and the lowest reading was 0.3 Mbps.

In terms of failure pattern, Pathload tools produce all results for twenty cycles. . The result produce by Pathload was between the benchmark stated that was from 1 Mbps to 54Mbps.Therefore, shows that Pathload has 0% of failure pattern.

For the accuracy, 90% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. 10 % of the reading were below the benchmark that has been set. The lower reading or over the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathload was 1.805 and the SD was 0.6621.

3. Wbest.

Table 11 shows the reading and the result of Wbest for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table.

Wbest	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	0.3	-0.9	1.6	1.4	1.4	0.6	-4.1	1.4	1.9	0.3
Wbest	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	-0.8	0.2	0.3	1.5	0.02	0.8	-9.3	1.6	-1.7	-2.2

Table 11 Wbest readings

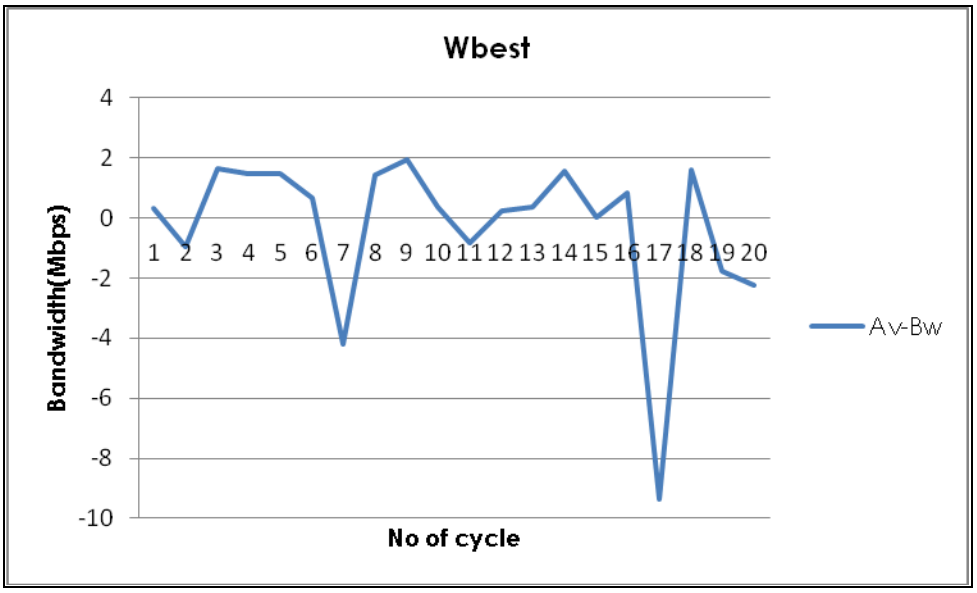

Figure 24 Wbest graph

From the figure 24, we can see that Wbest was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 1.938 Mbps and the lowest reading was 1.43 Mbps.

In terms of failure pattern, Wbest tools produce all results for twenty cycles. There were 15 readings which were not valid since it does not match the benchmark that was being stated. The benchmark that was used in this experimental analysis was between 1Mbps to 54Mbps. Therefore, it shows that Wbest has 75% of failure pattern.

For the accuracy, 25% of the estimated readings were in the range of the benchmark that has been set while 75% of the reading was below the benchmark. The range of the benchmark that has been set was between 1Mbps to 54Mps

For the consistency, the mean and standard deviation were calculated. The mean for the Wbest was 0.70245 and the SD was 0.7178

C. Two routers with the different bandwidth

1. Pathrate

Table 12 shows the reading and the result of Pathrate for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table.

Pathrate	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	6.4	6.2	7.0	5.0	6.5	7.2	5.2	5.3	6.5	5.4
Pathrate	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	8.2	6.7	6.8	6.3	7.1	6.0	5.9	5.4	6.3	6.2

Table 12 Pathrate readings

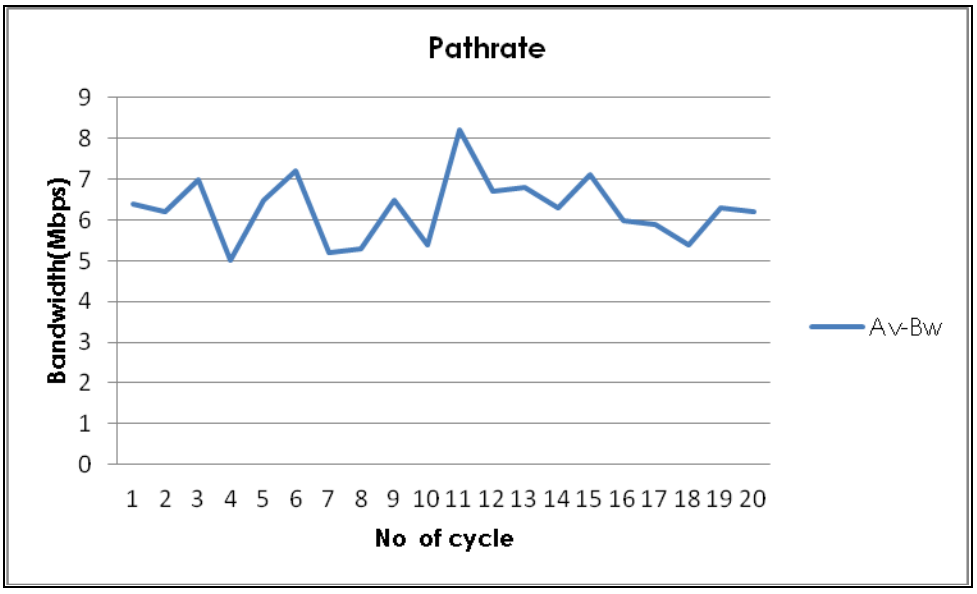

Figure 25 Pathrate graph

From figure 25, we can see that Pathrate was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 8.2 Mbps and the lowest reading was 5.0 Mbps.

In terms of failure pattern, Pathrate tools produce all results for twenty cycles. The result produce by Pathrate was between the benchmark stated that was from 1 Mbps to 54Mbps.Therefore, shows that Pathrate has 0% of failure pattern.

For the accuracy, 100% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. The lower reading or over the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathrate was 6.305 and the SD was 0.8268.

2. Pathload.

Table 13 shows the reading and the result of Pathload for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table.

Pathload	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	1.3	1.9	2.2	2.1	1.2	1.0	1.5	1.2	2.1	2.3
Pathload	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	0.7	0.7	1.5	1.9	1.1	1.8	1.2	1.4	1.4	1.5

Table 13 Pathload readings

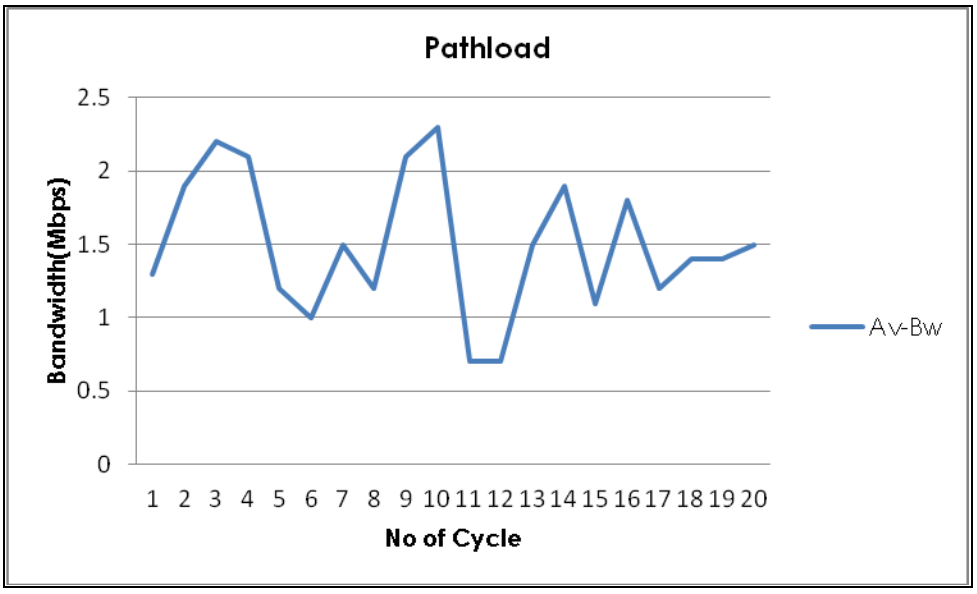

Figure 26 Pathload graph

From figure 26, we can see that Pathload was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 2.3 Mbps and the lowest reading was 0.7 Mbps.

In terms of failure pattern, Pathload tools produce all results for twenty cycles. . The result produce by Pathload was between the benchmark stated that was from 1 Mbps to 54Mbps.Therefore, shows that Pathload has 0% of failure pattern.

For the accuracy, 90% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. 10 % of the reading were below the benchmark that has been set.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathload was 1.5 and the SD was 0.4746.

3. Wbest.

Table 14 shows the reading and the result of Wbest for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table.

Wbest	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	-2.2	0	-4.9	1.9	0.3	-9.3	-0.1	-1.6	-0.1	1.1
Wbest	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	-6.1	-0.2	1.6	-1.6	-7.0	-4.6	0.7	0.5	-5.5	0.9

Table 14 Wbest readings

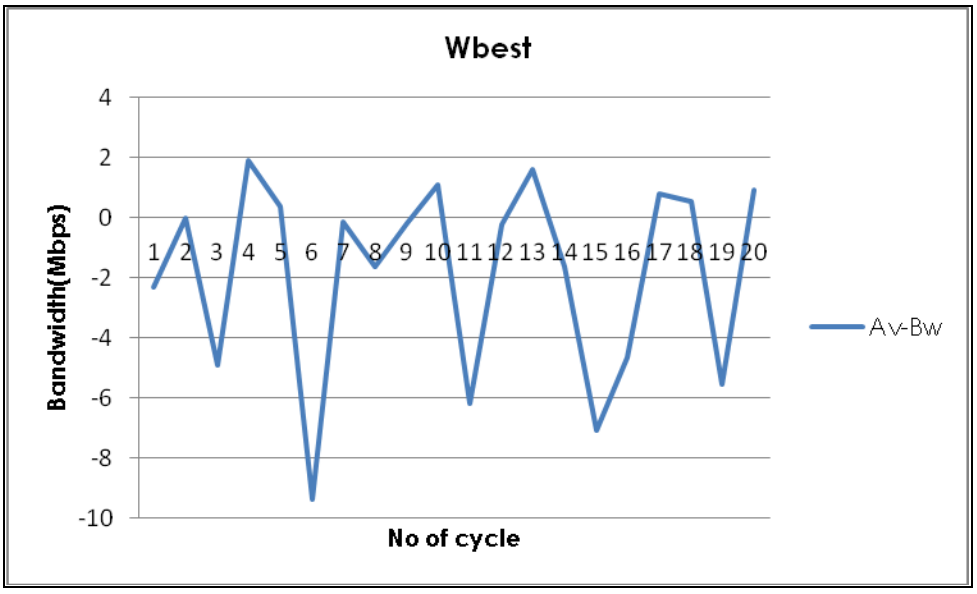

Figure 27 Wbest graph

From the graph, we can see that Wbest was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 1.916 Mbps and the lowest reading was 1.12 Mbps.

In terms of failure pattern, Wbest tools produce all results for twenty cycles. There were 16 readings which were not valid since it does not match the benchmark that was being stated. The benchmark that was used in this experimental analysis was between 1Mbps to 54Mbps. Therefore, it shows that Wbest has 80 % of failure pattern.

For the accuracy, 20% of the estimated readings were in the range of the benchmark that has been set while 80% of the reading was below the benchmark. The benchmark that has been set was between 1Mbps to 54Mps. The lower reading or overestimated reading of the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Wbest was 0.4483 and the SD was 0.6599

5.1.2 Network with External Traffic.

In this testing, the available bandwidth of each tool was recorded for 20 cycles. Different result was recorded based on the tool used

A. One router (FTP).

1. Pathrate

Table 15 shows the reading and the result of Pathrate for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table

Pathrate	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	5.9	5.3	5.5	6.6	7.7	5.5	5.9	5.5	6.2	6.4
Pathrate	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	8.6	5.5	5.9	6.1	5.8	6.2	5.7	5.7	6.0	5.9

Table 15 Pathrate readings

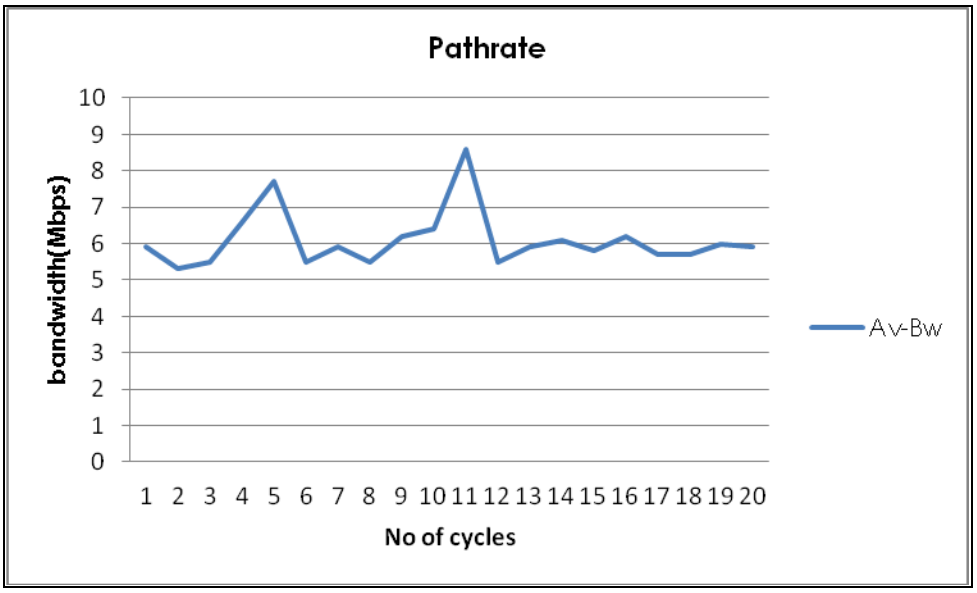

Figure 28 Pathrate graph

From figure 28, we can see that Pathrate was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 8.6 Mbps and the lowest reading was 5.3 Mbps.

In terms of failure pattern, Pathrate tools produce all results for twenty cycles. The result produce by Pathrate was between the benchmark stated that was from 1 Mbps to 54Mbps.Therefore, shows that Pathrate has 0% of failure pattern.

For the accuracy, 100% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. The lower reading or overestimated reading of the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathrate was 6.07 and the SD was 0.8033.

2. Pathload.

Table 16 shows the reading and the result of Pathload for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table

Pathload	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Av-Bw	1.3	4.0	0.7	2.2	0.4	1.4	1.3	0.4	1.7	4.4
Pathload	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Av-Bw	4.8	1.1	1.2	0.8	0.7	0.8	0.7	1.1	1.1	2.2

Table 16 Pathload readings

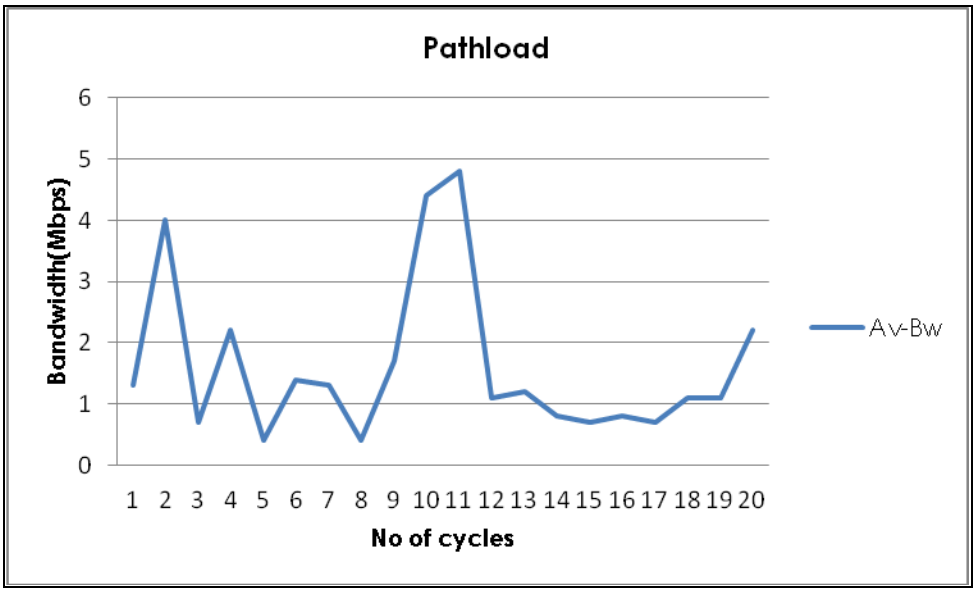

Figure 29 Pathload graph

From the graph, we can see that Pathload was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth .The default bandwidth used in this experiment was 54Mbps. The highest reading was 4.8 Mbps and the lowest reading was 0.4 Mbps.

In terms of failure pattern, Pathload tools produce all results for twenty cycles. . The result produce by Pathload was between the benchmark stated that was from 1 Mbps to 54Mbps.Therefore, shows that Pathload has 0% of failure pattern.

For the accuracy, 70% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. 30 5 of the reading was below the benchmark that has been set.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathload was 1.615 and the SD was 1.3035.

3. Wbest

Table 17 shows the reading and the result of Wbest for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table

Wbest	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	0	0	0	0	0	0	0	0	0	1.85
Wbest	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	0	0	0	0	0	0	0	4.64	0	0

Table 17 Wbest readings

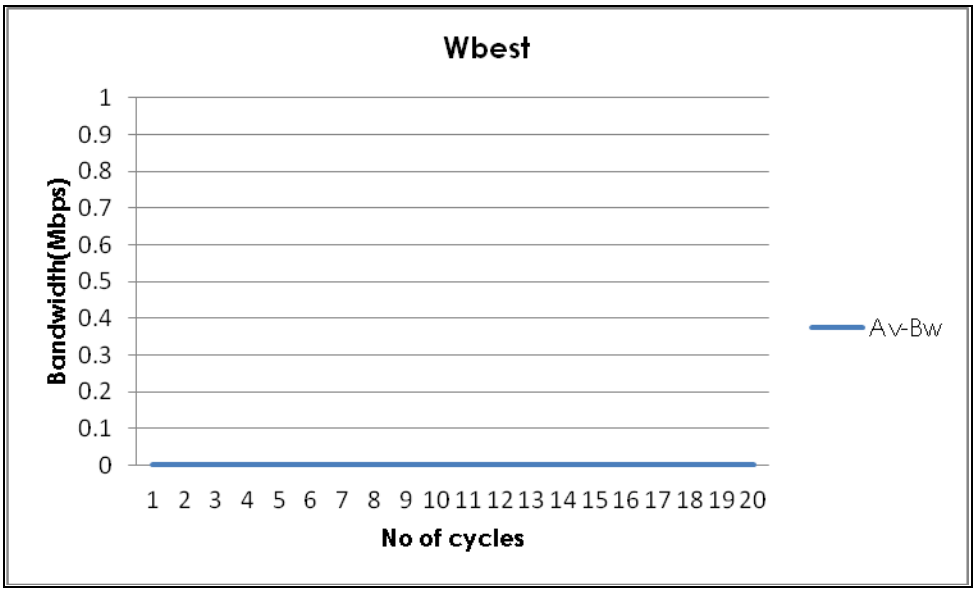

Figure 29 Wbest graphs

From figure 34, we can see that Wbest does not able to produce any result for each cycle. The default bandwidth used in this experiment was 54Mbps.

In terms of failure pattern, Wbest tool does not produce any result for twenty cycles. Therefore, shows that Wbest has 100% of failure.

For the accuracy, there was no result recorded when Wbest was used to the presence of FTP.

For the consistency, there was no data recorded when Wbest was used to indicate that Wbest cannot be used to estimate the available bandwidth when there was a network with external traffic.

B. Two routers with the same bandwidth

1. Pathrate

Table 18 shows the reading and the result of Pathrate for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table

Pathrate	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	5.0	4.9	3.8	4.6	4.1	6.1	4.1	4.7	5.6	5.8
Pathrate	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	6.6	4.1	6.1	4.8	5.3	5.4	4.1	4.6	4.7	5.9

Table 18 Pathrate readings

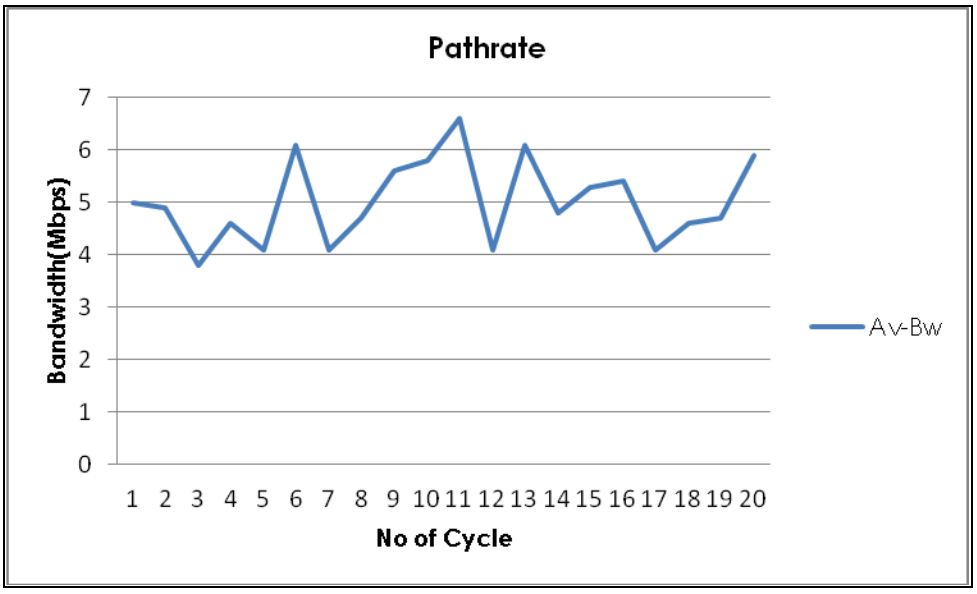

Figure 30 Pathrate graph

From figure 30, we can see that Pathrate was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 6.6 Mbps and the lowest reading was 3.8 Mbps.

In terms of failure pattern, Pathrate tools produce all results for twenty cycles. The result produce by Pathrate was between the benchmark stated that was from 1 Mbps to 54Mbps.Therefore, shows that Pathrate has 0% of failure pattern.

For the accuracy, 100% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. The lower reading or overestimated reading of the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathrate was 5.015 and the SD was 0.8034.

2. Pathload.

Table 19 shows the reading and the result of Pathload for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table

Pathload	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	1.2	0.7	0.2	0.4	1.0	0.6	0.4	0.5	0.4	0.7
Pathload	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	0.5	1.7	2.0	2.0	1.5	2.3	1.7	1.1	1.6	1.9

Table 19 Pathload readings

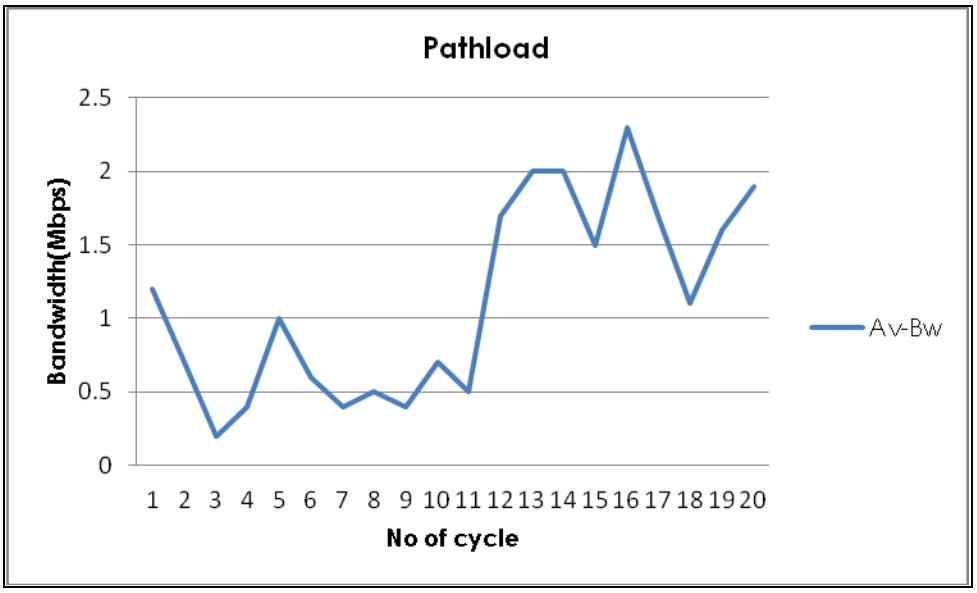

Figure 31 Pathload graph

From figure 31, we can see that Pathload was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 2.3 Mbps and the lowest reading was 0.2 Mbps.

In terms of failure pattern, Pathload tools produce all results for twenty cycles. . The result produce by Pathload was between the benchmark stated that was from 1 Mbps to 54Mbps.Therefore, shows that Pathload has 0% of failure pattern.

For the accuracy, 100% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. The lower reading or overestimated reading of the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathload was 1.12 and the SD was 0.6653.

3. Wbest.

Table 20 shows the reading and the result of Wbest for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table

Wbest	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	-11	-10	-19.6	-7.4	-26.6	0	-15.8	-24.9	-12.6	-32.5
Wbest	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	-15.9	-21.8	1.	3.9	-0.0	-3.5	-9.1	-14.5	-5.8	-39.2

Table 20 Wbest readings

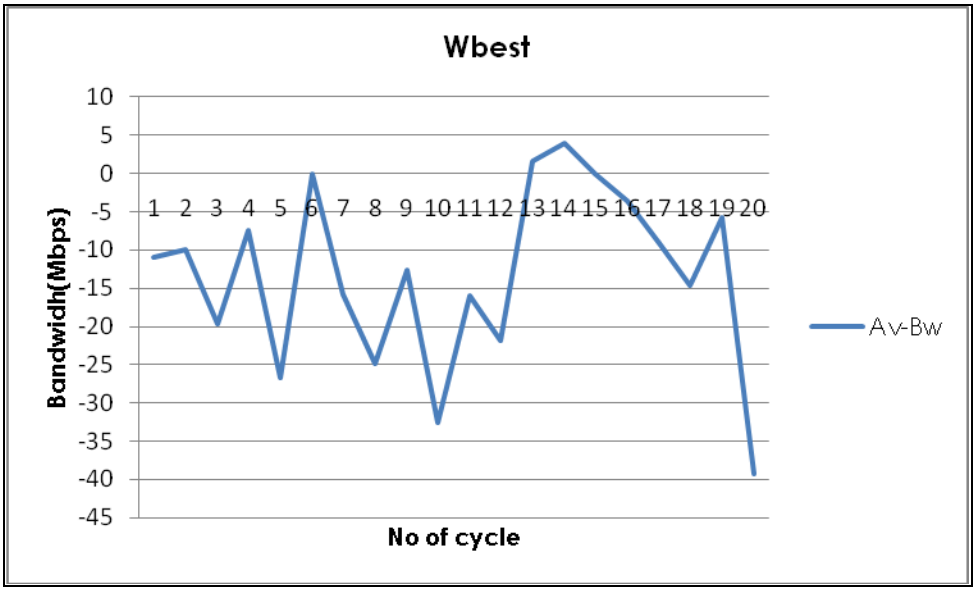

Figure 32 Wbest graph

From figure 32, we can see that Wbest was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 3.894 Mbps and the lowest reading was 1.678Mbps.

In terms of failure pattern, Wbest tools produce all results for twenty cycles. There were five readings which were not valid since it does not match the benchmark that was being stated. The benchmark that was used in this experimental analysis was between 1Mbps to 54Mbps. Therefore, it shows that Wbest has 90% of failure pattern.

For the accuracy, 10% of the estimated readings were in the range of the benchmark that has been set while 90% of the reading was below the benchmark. The benchmark that has been set was between 1Mbps to 54Mps. The lower reading or overestimated reading of the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Wbest was 0.2786 and the SD was 0.9298

C. Two routers with the differ bandwidth.

1. Pathrate

Table 21 shows the reading and the result of Pathrate for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table

Pathrate	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	4.3	4.4	4.3	4.6	3.2	3.8	5.6	6.9	5.2	5.7
Pathrate	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	7.2	5.4	6.3	5.6	4.2	4.4	4.1	4.3	3.4	4.6

Table 21 Pathrate readings

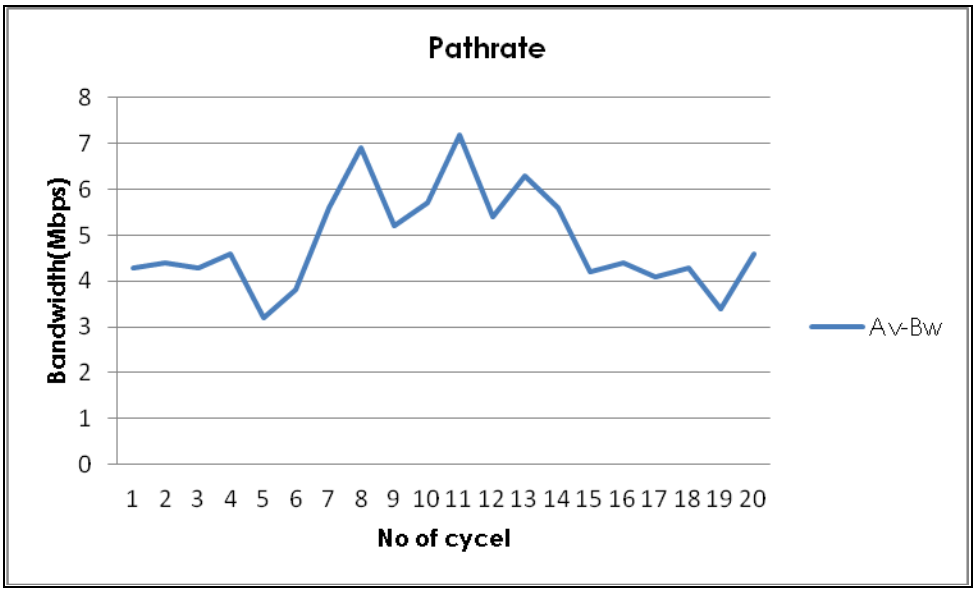

Figure 33 Pathrate graph

From figure 33, we can see that Pathrate was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 7.2 Mbps and the lowest reading was 3.2 Mbps.

In terms of failure pattern, Pathrate tools produce all results for twenty cycles. The result produce by Pathrate was between the benchmark stated that was from 1 Mbps to 54Mbps.Therefore, shows that Pathrate has 0% of failure pattern.

For the accuracy, 100% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. The lower reading or overestimated reading of the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathrate was 4.875 and the SD was 1.0867.

2. Pathload.

Table 22 shows the reading and the result of Pathload for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table

Pathload	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	1.3	1.2	1.2	1.1	1.3	0.7	1.1	0.6	1.1	1.5
Pathload	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	1.2	0.4	1.3	0.8	0.5	0.6	1.4	1.6	1.5	1.5

Table 22 Pathload readings

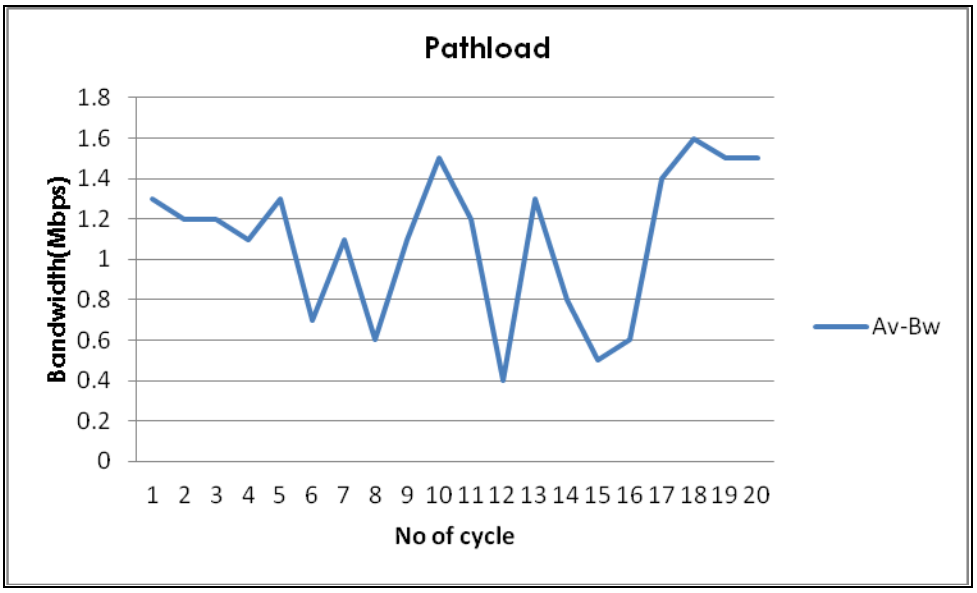

Figure 34 Pathload graph

From figure 34, we can see that Pathload was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth The default bandwidth used in this experiment was 54Mbps. The highest reading was 1.6 Mbps and the lowest reading was 0.4 Mbps.

In terms of failure pattern, Pathload tools produce all results for twenty cycles. There were six readings which were not valid since it does not match the benchmark that was being stated. The benchmark that was used in this experimental analysis was between 1Mbps to 54Mbps.Therefore shows that Pathload has 20 % of failure pattern.

For the accuracy, 70% of the estimated readings were in the range of the benchmark that has been set that was between 1Mbps to 54Mps. There is 30 % of the reading was lower than the benchmark set.

For the consistency, the mean and standard deviation were calculated. The mean for the Pathload was 1.095 and the SD was 0.3677.

3. Wbest.

Table 23 shows the reading and the result of Wbest for twenty cycles . For each cycle the rate of available bandwidth was taken out and recorded in the table

Wbest	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AV-Bw	0	-18.5	-0.7	0	-0.8	-0.5	-5.0	1.8	-4.6	-3.7
Wbest	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
AV-Bw	-0.7	-4.5	-1.8	0	-0.4	-3.0	-8.2	4.6	-12.2	-1.4

Table 23 Wbest readings

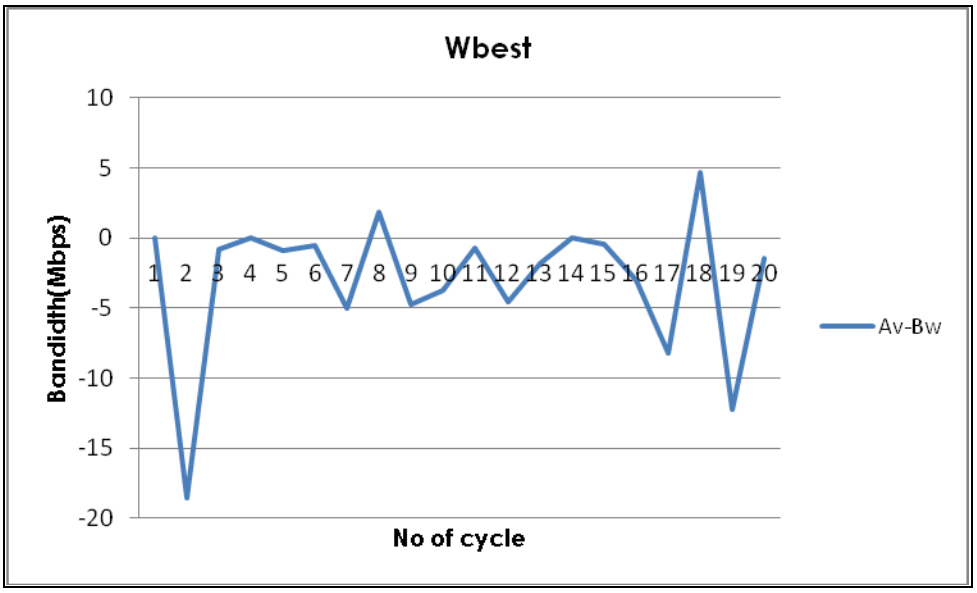

Figure 35Wbest graph

From figure 35, we can see that Wbest was able to produce the result for each cycle. Each cycle produced different rate of available bandwidth. The default bandwidth used in this experiment was 54Mbps. The highest reading was 4.647 Mbps and the lowest reading was 1.875Mbps.

In terms of failure pattern, Wbest tools produce all results for twenty cycles. There was eighteen reading which were not valid since it does not match the benchmark that was being stated. The benchmark that was used in this experimental analysis was between 1Mbps to 54Mbps. Therefore, it shows that Wbest has 90% of failure pattern.

For the accuracy, 10% of the estimated readings were in the range of the benchmark that has been set while 90% of the reading was below the benchmark. The benchmark that has been set was between 1Mbps to 54Mps. The lower reading or overestimated reading of the benchmark will be eliminated.

For the consistency, the mean and standard deviation were calculated. The mean for the Wbest was 0.3249 and the SD was 1.0980.

5.2 Result Discussion

5.2.1 Accuracy.

A. Optimum Network Condition.

The graph below shows the accuracy percentage based on the tools used

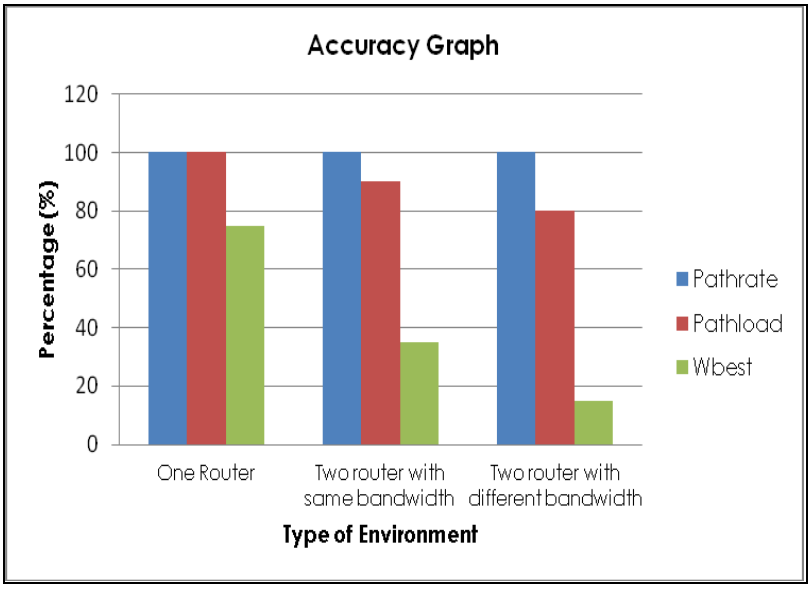

Figure 36 Accuracy for optimum network

Tools	One Router	Two routers with same bandwidth	Two routers with different bandwidth
Pathrate	100	100	100
Pathload	100	90	80
Wbest	75	35	15

Table 24 Accuracy table

From the table 24 and the graph it shows that, Pathrate was more accurate compared to Pathload and Wbest. From the graph we can see that Pathrate tool gave an accurate result in three types of scenarios. In each type of scenarios Pathrate gave 100 % of accuracy percentage.

B. Network with external traffic.

The graph below shows the accuracy percentage based on the tools used

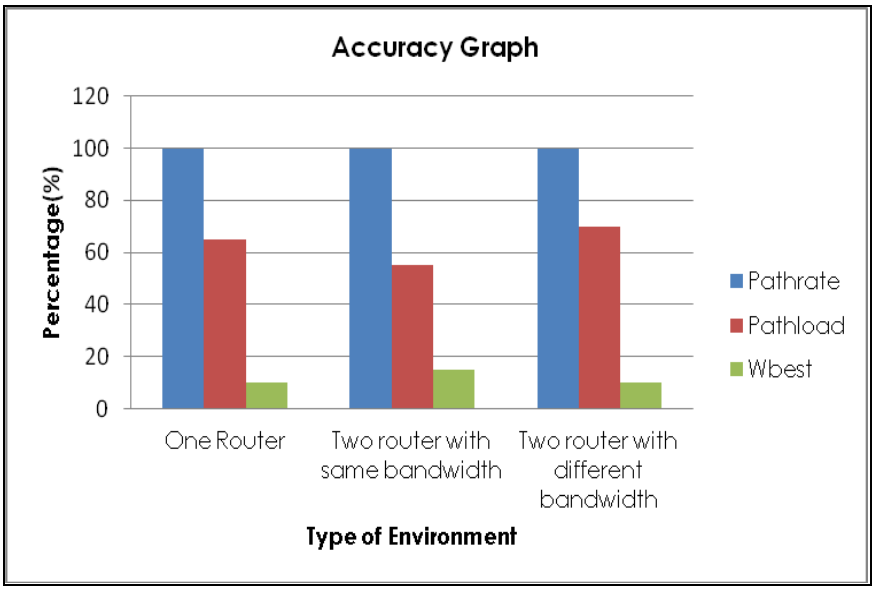

Figure 37 Accuracy for network with external traffic

Tools	One Router	Two routers with same bandwidth	Two routers with different bandwidth
Pathrate	100	100	100
Pathload	65	55	70
Wbest	10	15	10

Table 25 Accuracy table

From the table and the graph it shows that, Pathrate was more accurate compared to Pathload and Wbest. From the graph we can see that Pathrate tool gave an accurate result in three types of scenarios. In each type of scenarios Pathrate gave 100 % of accuracy percentage.

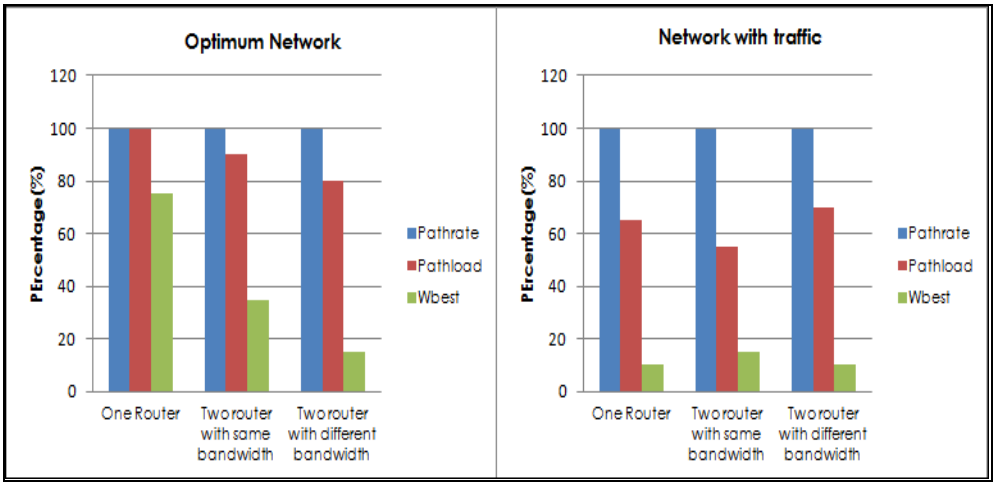

Figure 38 Accuracy for both environments.

As we can see from the figure 38, we can see that in both environments Pathrate has the highest percentage in term of accuracy in both environments which were optimum network and the network with the traffic. This was may be due to the characteristics of Pathrate where during the testing phase, it required a long time compared to the other tools made the reading become more accurate. It was also because Pathrate collects many packet pair measurements using various sizes of packets. Therefore, Pathrate tool was suitable to use to determine the accuracy of the available bandwidth.

5.2.2 Consistency of the tool.

A. Optimum Network Condition.

The graph below shows the consistency reading based on the tools used

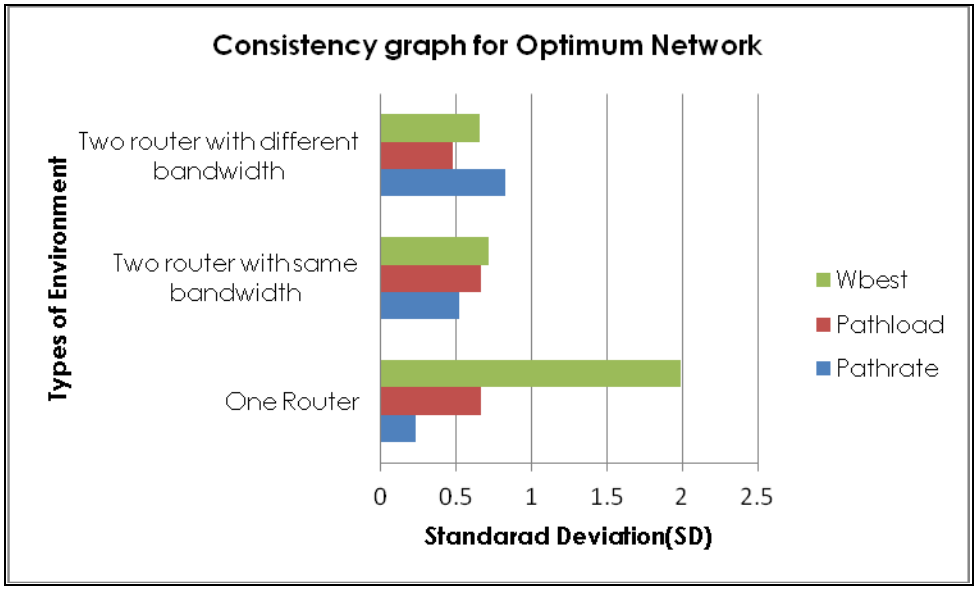

Figure 39 Consistency for optimum network

Tools	One Router	Two routers with same bandwidth	Two routers with different bandwidth
Pathrate	0.2291	0.5173	0.8268
Pathload	0.6682	0.6621	0.4746
Wbest	1.9844	0.7178	0.6599

Table 26 Consistency table.

From the table and the graph it shows that, for the one router scenario Pathrate tool has the highest value of standard deviation compared to Pathload and Wbest. For the two routers with the same bandwidth rate Pathrate gave the highest SD compare to others. In the third scenario where two routers with the higher bridging was used Pathload gave the highest SD value.

B. Network with external traffic.

The graph below shows the consistency reading based on the tools used

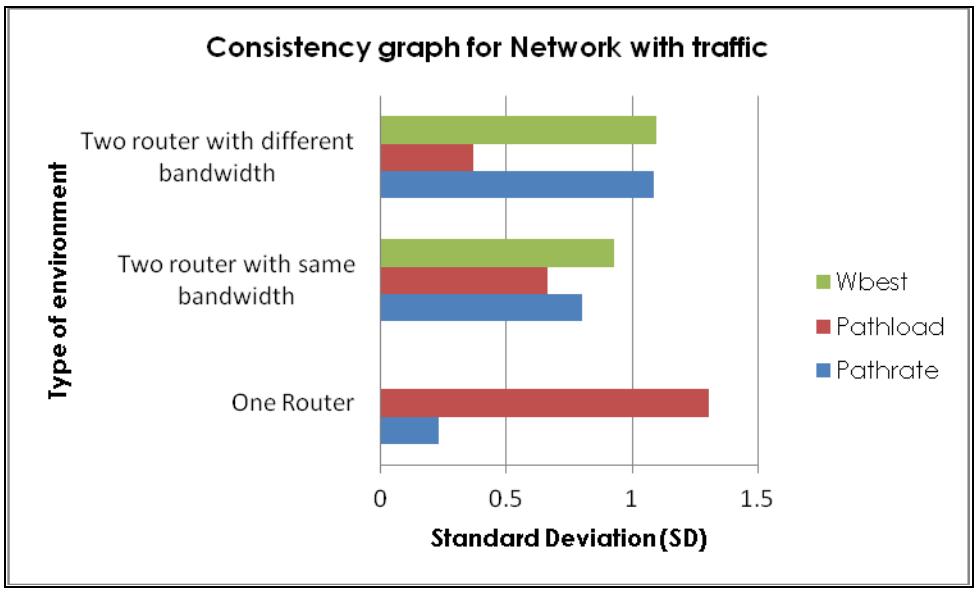

Figure 40 Consistency for network with external traffic

Tools	One Router	Two routers with same bandwidth	Two routers with different bandwidth
Pathrate	0.2291	0.8034	1.0867
Pathload	1.3035	0.6653	0.3677
Wbest	0.0	0.9298	1.0980

Table 27 Accuracy table

From the table and the graph it shows that, for the one router scenario Wbest tool has the highest value of standard deviation compared to Pathrate and Pathload. For the two routers with the same bandwidth rate Pathload gave the highest SD compare to Pathrate. In the third scenario where two routers with the higher bridging were used Pathload gave the highest SD value.

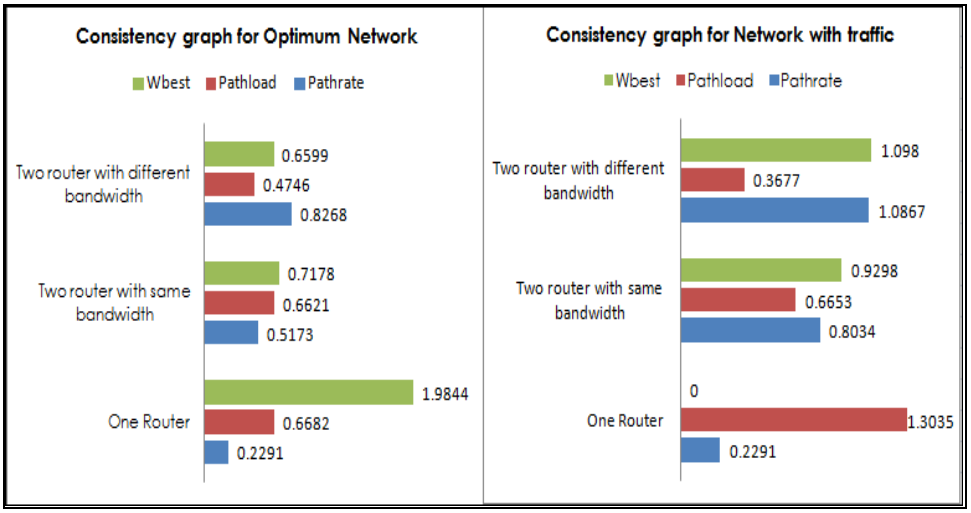

Figure 41 Consistency for both environments.

As we can see from the figure 41, it shows the consistency graph for both environments. In terms of consistency, the tool that shows the lowest reading of SD was the most consistent tools to be used. From the graph we can see that Pathrate has the lowest standard deviation compare to others too. This was maybe due to the Pathrate characteristic .Pathrate used the long packet train to estimate the dispersions path. The lower bound provides reliable reading on the path since the dispersion rate was larger. Therefore for both situations, Pathrate tool was determined to be used.

5.2.3 Failure pattern.

A. Optimum Network Condition.

The graph below shows the failure pattern graph based on the tools used

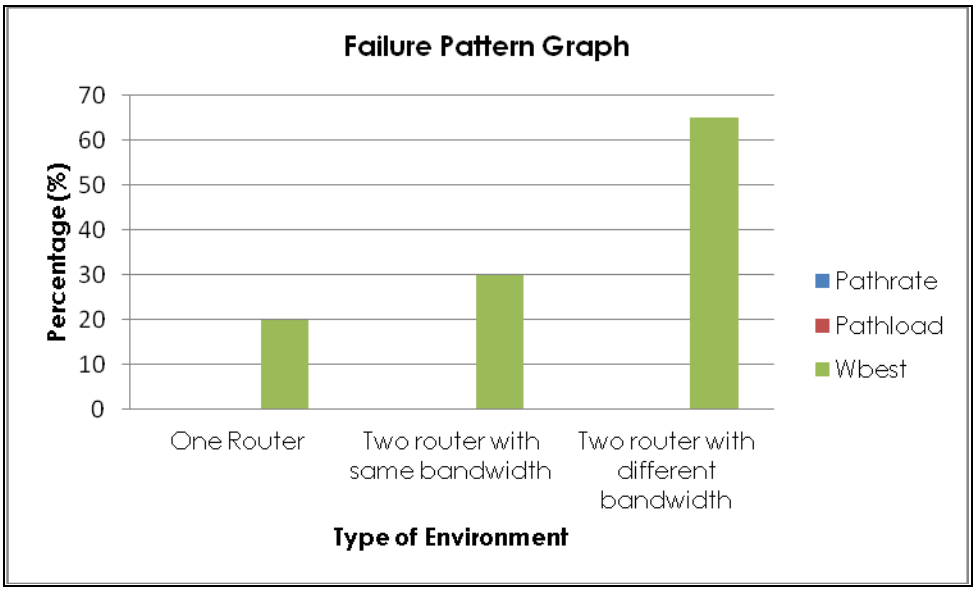

Figure 41 Failure Pattern for optimum network

Tools	One Router	Two routers with same bandwidth	Two routers with different bandwidth
Pathrate	0	0	0
Pathload	0	0	0
Wbest	20	30	65

Table 28 Failure pattern table

From the table and the graph it shows that, Pathrate and Pathload has no failure pattern in their readings. Both tools successfully produced a reading for each type of environment that was used during testing. This is maybe due to the characteristics of both tools which were, both tools used packet-trains and packet-dispersion to measure the available bandwidth.

B. Network with external traffic.

The graph below shows the accuracy percentage based on the tools used

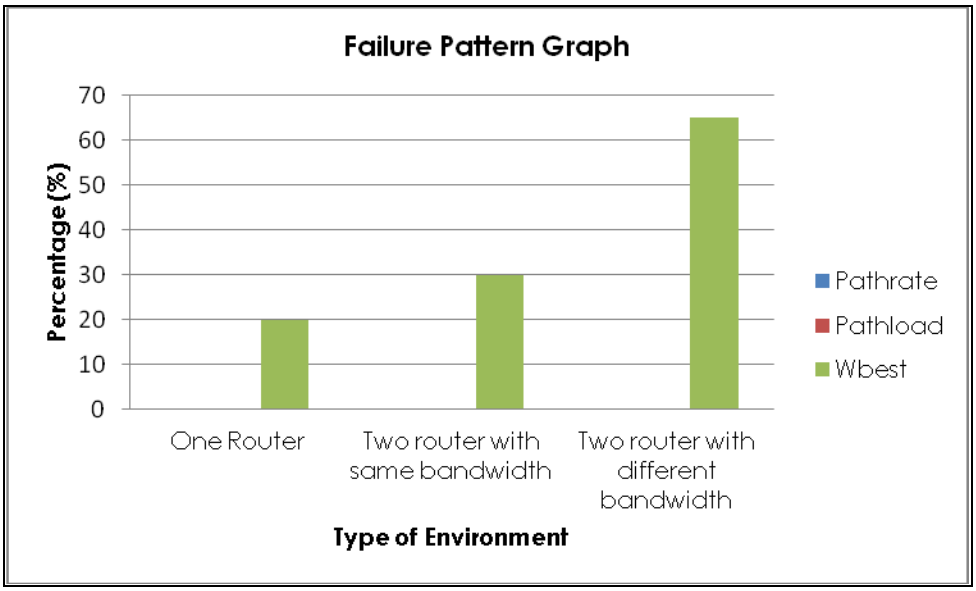

Figure 42 Consistency for network with external traffic

Tools	One Router	Two routers with same bandwidth	Two routers with different bandwidth
Pathrate	0	0	0
Pathload	0	0	0
Wbest	20	30	65

Table 29 Failure pattern table

From the table and the graph it shows that, Pathrate and Pathload has no failure pattern in their readings. Both tools successfully produced a reading for each type of environment that was used during testing.

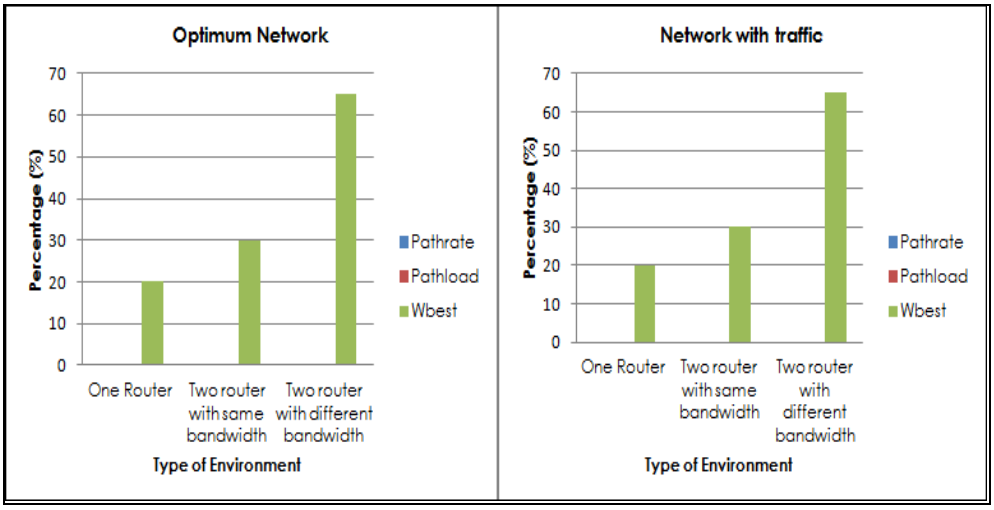

Figure 43 Failure pattern graph for both environments.

As we can see from the figure 49, it shows the failure pattern graph for both environments. In terms of failure pattern, the tools were determined by the reading of the tools. The reading of the tools was determined by the benchmark that has been set which were 1 Mbps to 54Mbps. Different tools produced different reading. For this experimental analysis, both Pathload and Pathrate has the lowest percentage of failure pattern.

Therefore, Pathload and Pathrate were the best tools to be used to estimate the failure pattern of the available bandwidth. This was due to the Pathload and Pathrate characteristics. Pathload was based on the Self Loading Periodic Streams methodology. It was based on the idea that the one-way delays of periodic packet stream show an increasing trend when the stream's rate is higher that the available bandwidth. Pathrate was end to end tools that used packet-pairs and packet-trains dispersion technique, to estimate the bandwidth capacity of the network.

CHAPTER 6

CONCLUSION

6.0 Conclusion.

Wireless local area networks (WLANs) were widely used in our world nowadays. The widespread use of WLAN has increase an interest of researchers to do the experiment on various fields of WLAN over the bandwidth estimation. In the 802.11g wireless environment, we evaluated the accuracy of the tools, consistency reading of the tools and the failure pattern of the tools. Wbest , Pathrate , Pathload were the tools that have been used in this experimental analysis. To perform these experimental analysis twenty readings from each tool was recorded in different type of environment.

There were two types of environment which were optimum network and network with optimized network. For each environment there were three types of scenarios where all the tools were tested by using one router, two routers with the same bandwidth and two routers with different bandwidth. Theoretically Wbest which had been developed and tested on the 802.11 g platform should have outperformed the rest [ ]. However in this experiment that was not the result.

Based on the eighteen experiments that were done on the tools Pathrate , Wbest , and Pathload in two different environments, it shows that Pathrate was the most suitable tools to be used for both environments which were optimum network and network with traffic where the File Transfering Protocol (FTP) was used for three different scenarios.

Pathrate shows a 100 % percentage of accuracy for both environments on three different scenarios compared to the Pathload and Wbest. In terms of consistency also, Pathrate gave the most consistent reading compared to the others. The reading of the consistency was determined by the benchmark. The benchmark for this experiment was 1Mbps to 54bps. Pathrate gave the lowest standard deviation (SD) value which was 0.6154. Based on the failure pattern parameters, Pathrate and Pathload tools were the best the suitable tools to be used to determine it.

From all of the tools Wbest is not the most preferable tools to be used in both environments especially in network with traffic environment. Therefore, based on the accuracy, consistency and failure pattern, it shows that Pathrate was the best recommended tools to be used for both environments which were optimum network and network with traffic on three different types of scenarios.

6.1 Recommendations

There were a few limitations regarding this experimental analysis. By considering the outcomes of the results and the scope the project, the following recommendation as proposed for future works on available bandwidth and the bandwidth estimation tool

The following were the recommendations for the future works:

- In the future works, the research can be done by using different types of bandwidth estimation tools
- Extensive experiments can be done by varying the parameters to interference, rate of adoption, link capacity , time consumption across the traffic, signal noise to ratio and others
- The future research also can be done by extending the research to IEE 802.11n, GPRS, and 3G networks
- The future research also can focus on implementing QOS algorithm at access point itself to further look at the effects on the bandwidth estimation tools.

REFERENCES

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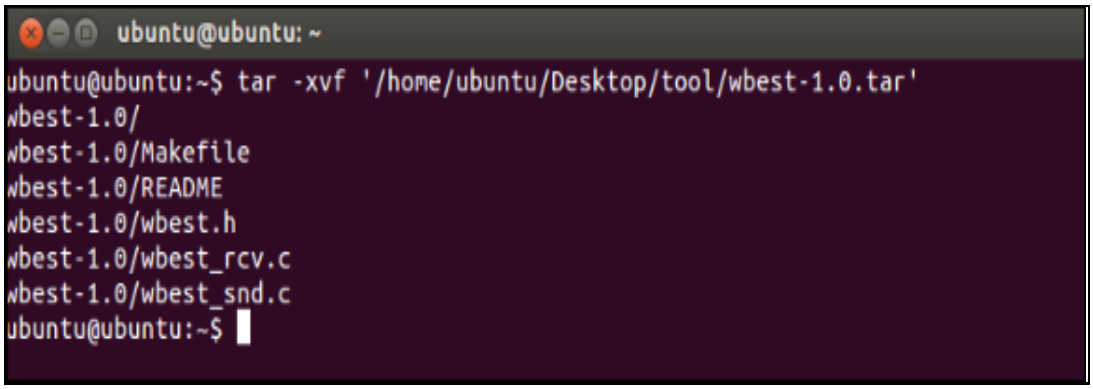
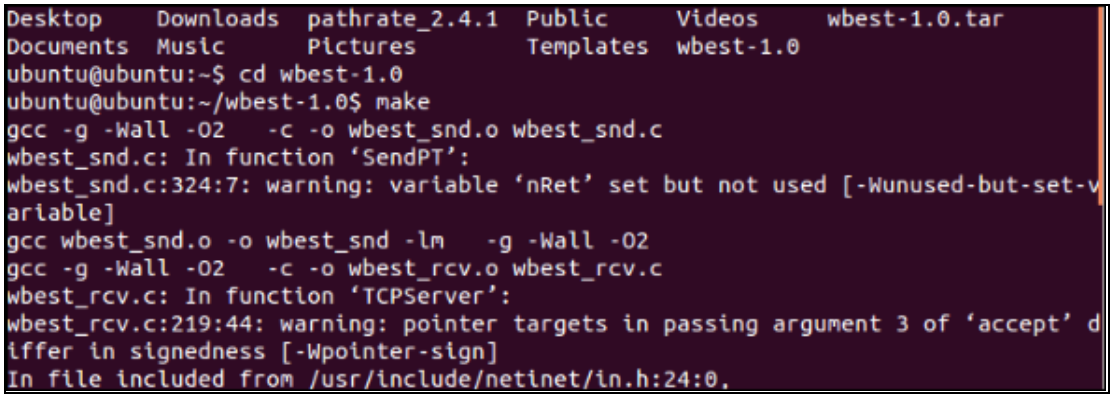
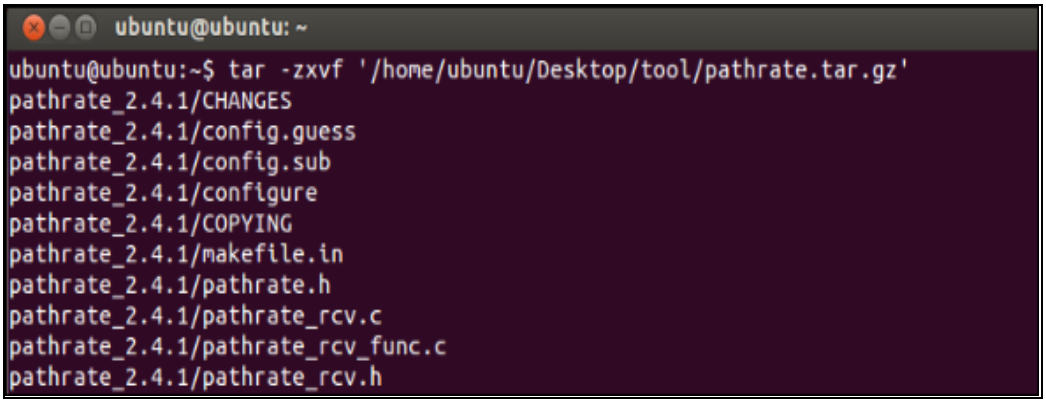
APPENDICES

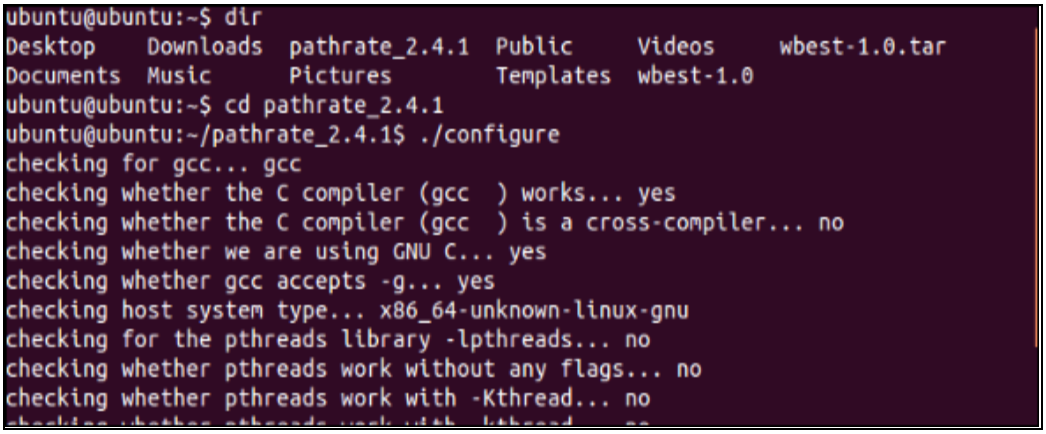
APPENDIX 1: Wbest installation and configuration.



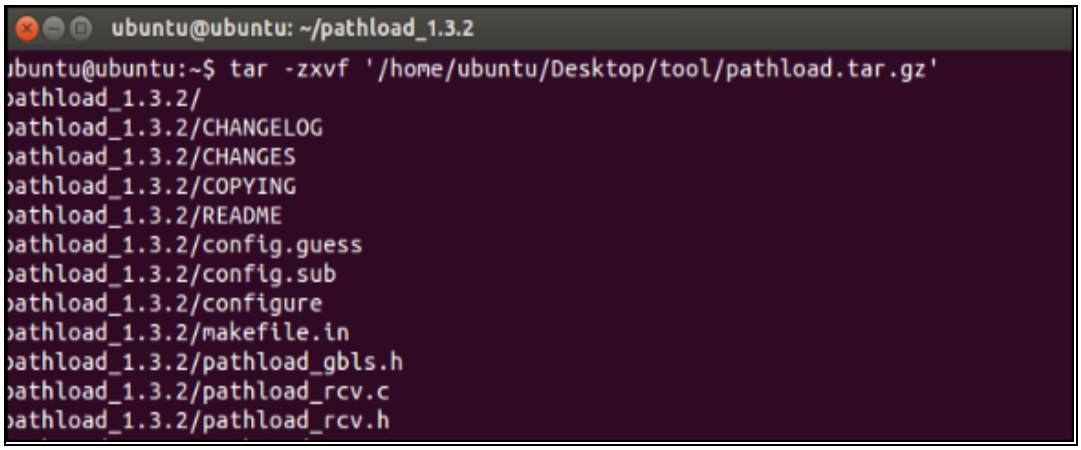


APPENDIX 2: Pathrate installation and configuration.



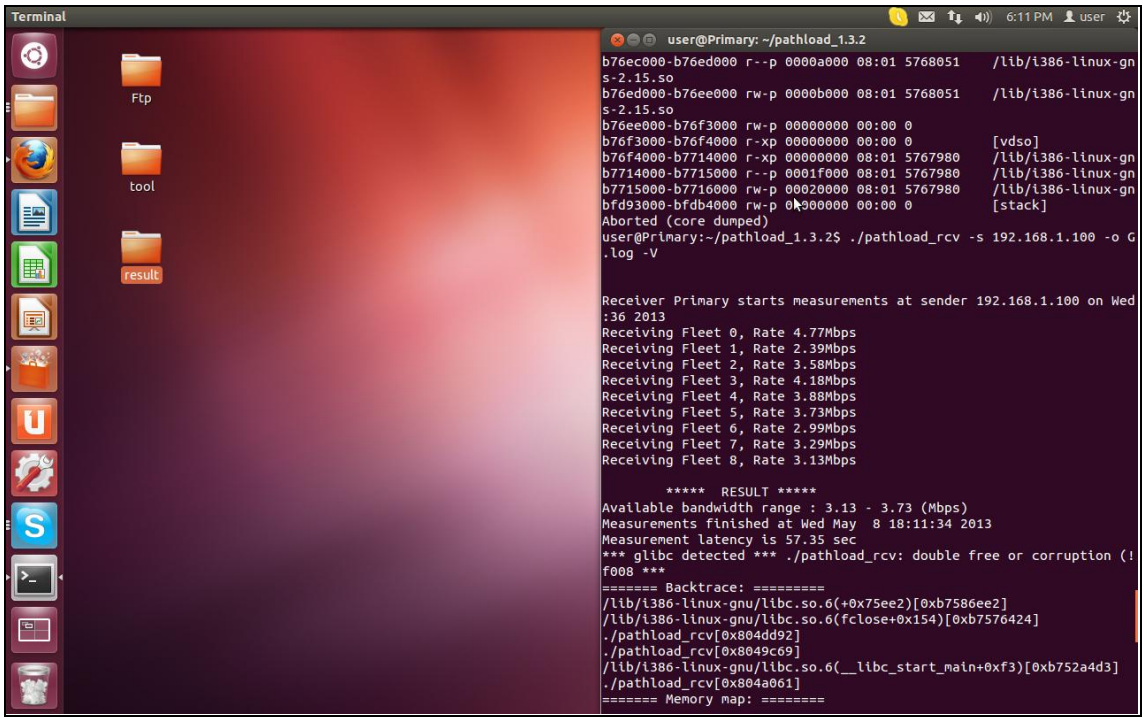


APPENDIX 3: Pathload installation and configuration.

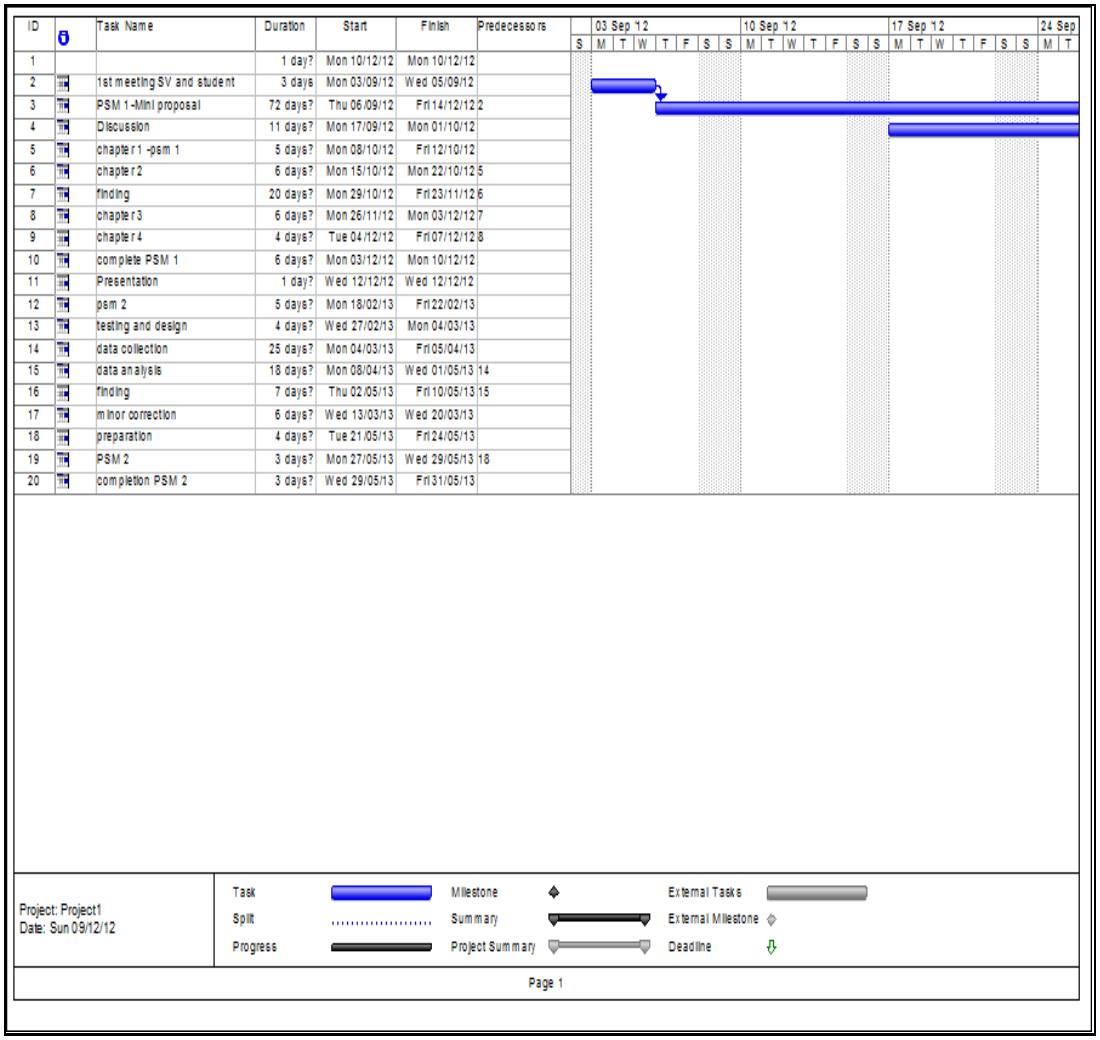


```
bash: /configure: No such file or directory
ubuntu@ubuntu:~/pathload_1.3.2$ ./configure
checking for gcc... gcc
checking whether the C compiler (gcc  ) works... yes
checking whether the C compiler (gcc  ) is a cross-compiler... no
checking whether we are using GNU C... yes
checking whether gcc accepts -g... yes
checking host system type... x86_64-unknown-linux-gnu
checking for the pthreads library -lpthreads... no
checking whether pthreads work without any flags... no
checking whether pthreads work with -Kthread... no
checking whether pthreads work with -kthread... no
```

APPENDIX 4: Example of data capture (using Pathload)



APPENDIX 5: Gantt chart.



ID	Task Name	Duration	Start	Finish	Predecessors
1		1 day?	Mon 10/12/12	Mon 10/12/12	
2	1st meeting SV and student	3 days	Mon 03/09/12	Wed 05/09/12	
3	PSM 1-Mini proposal	72 days?	Thu 06/09/12	Fri 14/12/12	2
4	Discussion	11 days?	Mon 17/09/12	Mon 01/10/12	
5	chapter 1 -psm 1	5 days?	Mon 08/10/12	Fri 12/10/12	
6	chapter 2	6 days?	Mon 15/10/12	Mon 22/10/12	5
7	finding	20 days?	Mon 29/10/12	Fri 23/11/12	6
8	chapter 3	6 days?	Mon 26/11/12	Mon 03/12/12	7
9	chapter 4	4 days?	Tue 04/12/12	Fri 07/12/12	8
10	complete PSM 1	6 days?	Mon 03/12/12	Mon 10/12/12	
11	Presentation	1 day?	Wed 12/12/12	Wed 12/12/12	
12	psm 2	5 days?	Mon 18/02/13	Fri 22/02/13	
13	testing and design	4 days?	Wed 27/02/13	Mon 04/03/13	
14	data collection	25 days?	Mon 04/03/13	Fri 05/04/13	
15	data analysis	18 days?	Mon 08/04/13	Wed 01/05/13	14
16	finding	7 days?	Thu 02/05/13	Fri 10/05/13	15
17	minor correction	6 days?	Wed 13/03/13	Wed 20/03/13	
18	preparation	4 days?	Tue 21/05/13	Fri 24/05/13	
19	PSM 2	3 days?	Mon 27/05/13	Wed 29/05/13	18
20	completion PSM 2	3 days?	Wed 29/05/13	Fri 31/05/13	

APPENDIX 6: Turnitin