EXPERIMENTAL ANALYSIS ON ACTIVE BANDWIDTH ESTIMATION TOOLS FOR MESH WIRELESS LOCAL AREA NETWORK (WLAN)

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ABSTRACT

Available bandwidth estimation is useful for route selection in a network environment. While many tools has been created to estimate the available bandwidth, mainly by two techniques passive and active 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 with the availability of multiple available bandwidth estimation tools around, the question is which bandwidth estimation tool will be the best to perform the task in a given network situation? Which tools perform the best when fluctuation of bandwidth happens in a network? In this research, the aim is to test a number of bandwidth estimation tools in active method by simulating traffic in a real testbed setup in open wireless environment. The focus is wireless environment, therefore it will be varies in terms of number of hops and bandwidth between excess points. To further test the tools, simulation will also be done on an optimum network and network with external traffic where other packet traffic happens to be around while the experiment is running. Expected result is dependable on the consistency result of each tool when tested with different wireless environment. Further recommendation will be given on which tool is suitable to use base on the testing result.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF GRAPH

Chapter 1

INTRODUCTION

1.0 Introduction

A wireless computer network (or wireless local area network, for wireless native space network, typically noted as field, for native space wireless network) is one within which a mobile user will connect with a local area network (LAN) through a wireless. The IEEE 802.11 cluster of standards specifies the technologies for wireless LANs. 802.11 standards use the LAN protocol related is CSMA/CA (carrier sense multiple access with collision avoidance) for path distribution and embrace an encoding technique, the Wired Equivalent Privacy formula. [1]

Commonly, a home and business WLAN employs one or two access points to broadcast a signal around a 100- to 200-foot radius. [2] The wireless technology and hardware in this category subscribes to the 802.11a, b, or g standards (also known as Wi-Fi); some home and office WLANs now adhere to the new 802.11n standard. [1]

The general used of wireless standard is 802.11g whereby will be used for this experimental project. 802.11g standard is the third generation of WLAN that use for home and business to give connectivity to the user to connect to the LAN. The first generation used is 802.11a continued by 802.11b although nowadays the 802.11n already release to be use by home and business user to connect to the LAN. All this standard have pros and cons that state at table below.

802.11 standard category	Advantage	Disadvantage
802.11a (up to 54Mbps)	Faster data transfer rates More concurrent connections supported Low vulnerable to the interference	Short range (60-100 feet) Less able to penetrate physical barriers
802.11b (up to 11Mbps)	Better at probing physical barriers Longest range (70-150 feet) Hardware is usually less expensive	Slower data transfer rates Doesn't support as many concurrent connections More vulnerable to interference
802.11g (up to 54Mbps)	Faster data transfer rates Better range than 802.11b (65-120 feet)	More vulnerable to interference
802.11n (up to 600Mbps)	The 802.11n standard was already approved by the Institute of Electrical and Electronics Engineers (IEEE), as compared to the previous three standards. Though specifications may change, it is expected to allow data transfer rates up to 600Mbps, and may offer larger ranges.	

Table 1: Several standards for WLAN. [2]

Bandwidth within the network context refers to the quantity of information which will be transmitted from one purpose to a different speed during a given period (usually in seconds) – data transfer rate. Network information measure metrics is expressed in bits (of data) per seconds (bps). Sometimes, during this era wherever demand in information measure is far higher, it's typically expressed in bytes per second (Bps). However, it ought to be noted and remembered that there's a distinction between information measure capability and offered information measure. [3]

Bandwidth capacity refers to the maximum data or throughput that can be transmitted on a link or a medium. It is important to understand and identify the maximum throughput of a link in network planning to cater the needs of the end user or end nodes. For example, for a normal user, it would be sufficient to have a link of Cat5 (Category 5) Ethernet cable of 100 Megabit per second (Mbit/s). [3]

The bandwidth can be measure by tool to define the speed, accuracy, failure and consistency of the network. There are a lot of tools available in the internet but not all can be used because due to upgrade of network technology nowadays. The tools can help network administrator to monitor the network which will be recommend by researcher in this project.

1.1 Problem Statement

The available bandwidth is a key factor in several network technologies. And in some circumstances, bandwidth may be a crucial factor between the success and failure of an application. Statistics have shown that in recent years, the growing number of Internet users has increased significantly. With the likes of Internet applications such as video and audio streaming, online games, video and audio downloading, Voice over IP (VoIP) and video conferencing, these has contributed to the increase of Internet users and which directly affects the bandwidth causing it to be highly utilize. Plus, with the rapid increase in Wi-Fi based devices providing mobility with more and more premises having Wi-Fi services, the need for wireless network bandwidth will be in demanding. Due to this situation, bandwidth estimation tools will be able to assist network administrators or planners to understand and have a clear picture of the available bandwidth of the current network connection so that proper measurements and planning can be taken to fully optimize the available bandwidth. However, most of the available bandwidth estimation tool were developed and tested on Wired LAN. The performance of these tools in the realm of wireless networks has not been evaluated extensively. Very little or minimal testing have been conducted to test these tools on a wireless network environment and most of it were tested on the simulation platform. Hence, an experimental test will be conducted to evaluate the bandwidth estimation tools operating in the wireless network environment. A comparative analysis will be carried out for the following attributes:

I. Accuracy: This will measure the accuracy of the tool to estimate the available bandwidth whether it will over estimate or under estimate the available bandwidth.

II. Failure patterns: This attribute will monitor and measure the reliability of the tool’s failure or error prone to estimate the bandwidth throughout the testing cycle.

III. Consistency of measurement: This attribute will measuring the consistency of the measurement of the tool as whether it will fluctuate of over estimating or under estimating the bandwidth.

1.2 Objective

This research was conducted to meet three objectives. The objectives of this research are:

- To measure available bandwidth with selected active bandwidth estimation tool in multiple network environment.
- To compare the selected tool based on their estimation preference in multiple network environments.
- To recommend the best bandwidth estimation tools for the given estimation tools

1.3. Scope

Due to the time and resources constraints and issues, this dissertation is limited in the following clauses:

- Five bandwidth estimation tools to be analyzed:- ASSOLO (2008), IGI/PTR (2003), Pathchirp (2003)
- IEEE 802.11 as the wireless network standard
- Bandwidth estimated reading from the tools is used in this experiment
- Twenty readings will be taken for each tool to ensure consistency in reading and data for each experiment analysis.
- Wireless hardware :- Two laptops with built in wireless 802.11b/g and two Linksys E1200 wireless router
- Experiment environment was done in open network to make sure the real situation is involved.
- Measurements are done generating any traffic on the link where the measurements are taken using tools that selected.

1.4 Thesis Organization

The research consists of five chapters:

Chapters 1 provide the overall overview of the thesis. Here, the problem statement will be introduced. Then 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 focuses 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 design the model or know as architecture that will be developed in order to perform the test. It then followed with the continuously design on data analysis.

Chapter 5 concludes all the chapters and the recommendations for future researchers explain most of the configurations of hardware and software involved in the research. Detail test result will be included in this chapter.

Chapter 2

LITERATURE REVIEW

2.0 IEEE Wireless 802.11 Network Technologies

The IEEE 802.11 specification (ISO/IEC 8802-11) is an international standard describing the characteristics of a wireless local area network (WLAN). Wireless local area network is also known as Wireless Fidelity (Wi-Fi). The name Wi-Fi sometimes incorrectly shortened to “WiFi” corresponds to the name of the certification given by the Wi-Fi Alliance, formerly WECA (Wireless Ethernet Compatibility Alliance), and the group which ensures compatibility between hardware devices that use the 802.11 standard. Today, due to misuse of the terms and for marketing purposes, the name of the standard is often confused with the name of the certification. A Wi-Fi network, in reality, is a network that complies with the 802.11 standard. [5]

With Wi-Fi, it is possible to create high-speed wireless local area networks, provided that the computer to be connected is not too far from the access point. Wi-Fi can be used to provide high-speed connections to laptop computers, desktop computers, personal digital assistants (PDAs) and any other devices located within a radius of several dozen meters indoors or within several hundred meters outdoors. [5]. The Speed of connection in general is 11 Mbps or greater because depend on technology used. The nodes in general can access the Wi-Fi with radius of 20m to 50m away.

2.1 Available Bandwidth

Bandwidth capacity refers to the maximum data or throughput that can be transmitted on a link or a medium. It is important to understand and identify the maximum throughput of a link in network planning to cater the needs of the end user or end nodes. The available bandwidth (ABW) at a link is its unused capacity. (See Figure 1 for the definitions used in this paper.) Since, at any time, a link is either idle or transmitting packets at the maximum speed, the definition of the available bandwidth ought to look at the average unused bandwidth over some time interval T. Thus,

$$A_i(t,T) = \frac{1}{T}\int_t^{T+t} (C_i - \lambda_i(t))\ dt,$$

Figure 1: Available bandwidth formula used in previous research [4]

Where Ai (t; T) is the available bandwidth at link *i* at time *t*, C_i is the link's capacity, and λ_i is its traffic. The available bandwidth along a path is the minimum available bandwidth of all traversed links. [4]

However, in the context of Internet path, it refers to the data or throughput that can be obtained by a transport protocol over that path. In short, it refers to the unused capacity of a link. Each paths available bandwidth relies heavily on the share of that path's bandwidth at a bottleneck link which is usually the slowest point in an end-to-end connection. Available bandwidth will be the crucial portion as business relies on available bandwidth and has recently received significant attention. It is important to determine or measure the available bandwidth as it will enable network planners to optimize resource utilization in traffic engineering and for admission control in quality of service (QoS), thus, maximizing profit and reduces cost to purchase for higher bandwidth.

There are mainly two techniques to estimate the available bandwidth – passive and active 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. And 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. But the question will be which bandwidth estimation tool will be the best to perform the task.

2.2 Impact for Different Environment

Wireless communication environment can be made in 802.11a, 802.11b, 802.11g and 802.11n. The 802.11g environment provides performance that may be similar to that of the 802.11a Wi-Fi standard that operates within the 5-GHz band, whereas providing backward compatibility with the gift 11-Mbps 802.11b standard. this combination of higher performance and backward compatibility is comparable in idea to the wildly productive and now-ubiquitous 100-Mbps Fast Ethernet standard from the wired LAN world.

In term of speed, each of environment will give a different speed but also depend on technology used whether 802.11a, 802.11b, 802.11g and 802.11n. The 802.11g is the most used today that give 54 Mbps maximum speed to user. The technology is also known as **physical standards** are that meaning to the 802.11 standard and offer different modes of operation, which lets them reach different data transfer speeds depending on their range.

Standard	Frequency	Speed	Modulation
WiFi a (802.11a)	5 GHz	54 Mbit/s	OMDF
WiFi B (802.11b)	2.4 GHz	11 Mbit/s	DSSS
WiFi G (802.11g)	2.4 GHz	54 Mbit/s	DSSS & OMDF
WiFi N (802.11n)	2.4 GHz & 5 GHz	600 Mbit/s	MIMO-OMDF

Table 2: Characteristics of Wireless Technology

2.2.1 802.11g Standard

The 802.11g standard can transmit maximum data transfer speed of 54 Mbps at ranges equal to those of the 802.11b standard. The 802.11g standard uses the 2.4GHz frequency range with OFDM. This standard is compatible with 802.11b devices, with the exception of some older devices [5]

The Speed by hypothetical	Indoors range	Outdoors range
54 Mbits/s	27 m	75 m
48 Mbits/s	29 m	100 m
36 Mbits/s	30 m	120 m
24 Mbit/s	42 m	140 m
18 Mbit/s	55 m	180 m
12 Mbit/s	64 m	250 m
9 Mbit/s	75 m	350 m
6 Mbit/s	90 m	400 m

Table 3: Hypothetical Speed for range in 802.11g

2.3 Active Bandwidth Estimation Tools

A bandwidth estimation tool is tools that can measure the bandwidth within end to end user or nodes. There is lot of tools that have been developed to measure the bandwidth available in the network. This tool will help administrator to measure the bandwidth reading due the network. The tool also can help administrator to define which network have a problem when the tools is tested to the specific network.

2.3.1 Assolo

End-to-end available bandwidth estimation is incredibly important for bandwidth dependent applications, quality of service verification and traffic engineering. Although many techniques and tools are developed in the past, producing reliable estimations in period of time still remains challenging - it's necessary to ensure that the measurement method is accurate, non-intrusive and robust to non-deterministic delays or traffic bursts.

ASSOLO could be a new active probing tool for estimating available bandwidth based on the concept of "self-induced congestion". ASSOLO features a replacement inquisitor traffic profile known as REACH (Reflected Exponential Chirp) which tests a large range of rates being a lot of accurate in the center of the inquisitor interval. Moreover, the tool runs inside a real-time operating system and uses some de-noising techniques to improve the activity method. Experimental results show that ASSOLO outperforms Pathchirp, a progressive measurement tool, estimating available bandwidth with larger accuracy and stability [6]

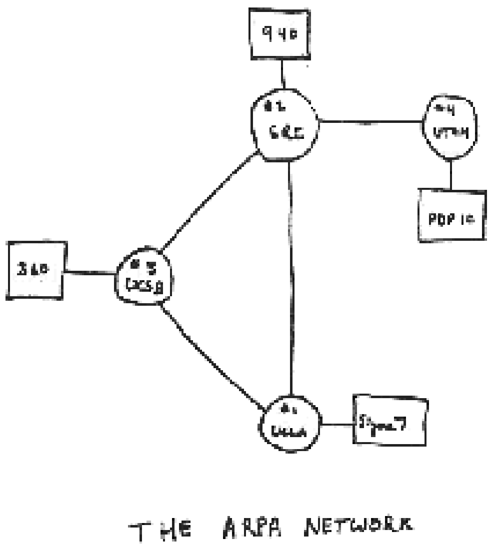


Figure 2: Assolo; Example of ARPA Network that use in previous research

2.3.2 (Initial Gap Increasing / Packet Transmission Rate)

This is an end-to-end available bandwidth measurement tool that uses active packet-train probing. Available bandwidth is defined as the residual bandwidth on the path, which can be calculated as path capacity minus path load. Using active probing to get accurate network measurement, we need carefully tune the probing parameters; probing packet size, number of probing packets, and initial probing gap.

Although all these parameters are important to induce correct measurement, initial probing gap is the most significant parameter to control for accurate available bandwidth measurement. the most accurate measurement is obtained when the packet-train sending rate at source equals its inbound rate at destination, where the initial packet combine gap that provides a high correlation between the packet gap changes and also the competing traffic throughput on the tight link. This IGI/PTR tool is intended supported this insight. IGI and PTR share the probing procedure, which is illustrated in the right figure. the main difference between them is that IGI focuses on calculating background traffic load, whereas PTR directly calculates packet transmission rate, to estimate end-to-end available bandwidth.[10]

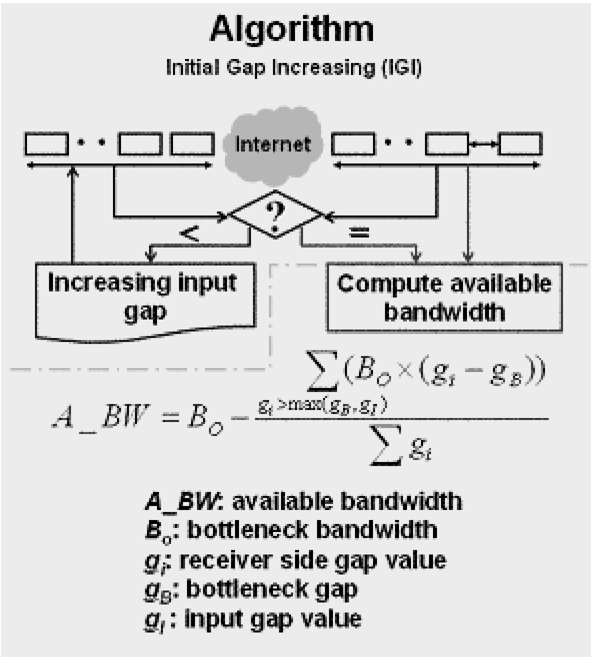


Figure 3: Algorithm of IGP

2.3.3 Pathchirp

Pathchirp is an active probing tool for estimating the available bandwidth on a communication network path. Based on the construct of "self-induced congestion," Pathchirp features an exponential flight pattern of probes we call a chirp. Packet chirps supply many significant benefits over current probing schemes based on packet pairs or packet trains. By rapidly increasing the probing rate among every chirp, Pathchirp obtains a rich set of data from which to dynamically estimate the available bandwidth [7]

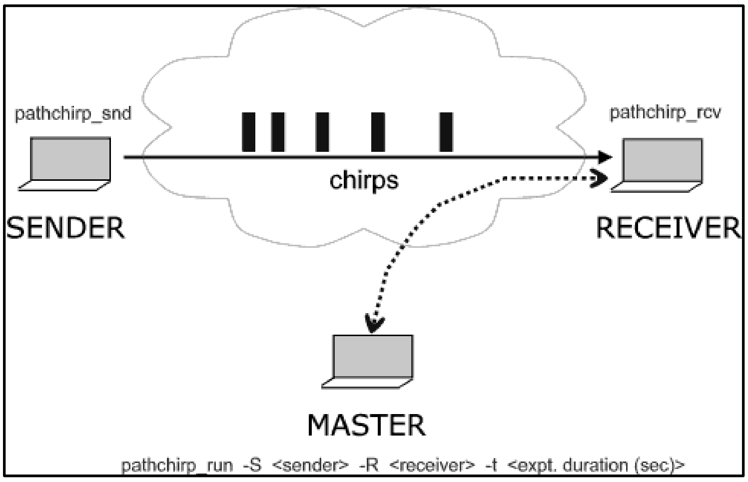


Figure 4: General architecture of Pathchirp

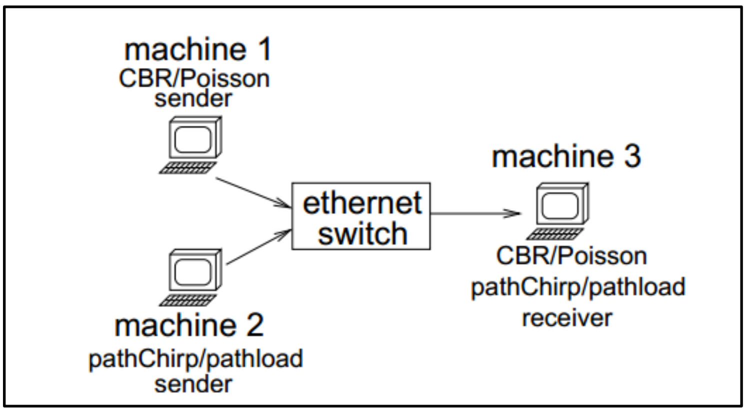


Figure 5: Architecture used for Pathchirp in the last research at Rice University

2.4 Comparison of other research

2.4.1 Assolo, a New Method for Available Bandwidth Estimation

This journal was written by Emanuele Goldoni, Giuseppe Rossi and Alberto Torelli that have been done in controlled environment. In this research, the researcher run the tool inside a real-time operating system and uses some de-noising techniques to improve the measurement process. The available bandwidth of a network path is a crucial metric in quality-of-service management, traffic engineering or congestion control. The measuring method used is tests a large varies of rates being more accurate in the center of the probing interval. Experimental results show that ASSOLO outperforms Pathchirp, a state of the art measuring tool, estimating available bandwidth with bigger accuracy and stability [6]

2.4.2 Comparative Analysis of Active Bandwidth Estimation Tools

This journal was written by Federico Montesino-Pouzols. This research is comparing several tools that consist of Cprobe, IGI/PTR, NetDyn, pathChrip, Pathload and others to analysis the bandwidth in the network. Several hosts at a LAN environment within a research institution connected to the Spanish NREN environment. The main of the made public is comparative analysis of progressive active inquiring tools for bandwidth estimation. The measuring technique is made public, ignoring implementation details of tools. These tests have been through with the aim to develop a set of practices, procedures and tools for the comparative analysis of active bandwidth estimation techniques and tools. As a result from the tests dole out, variety of failure conditions for the analyzed tools have been identified, in addition because the dependency of the estimates accuracy on factors like system load and network path properties [9]

2.4.3 Pathload: A measurement tool for end-to-end available bandwidth

This journal was written by Manish Jain and Constantinos Dovrolis. This research is conduct by using Pathload to measure available bandwidth in the network. From the study that have been made from this last research, the available bandwidth of a network path is the maximum throughput that can provide to a flow, without reducing the throughput of the cross traffic in the path .The basic idea in Pathload is that the unidirectional delays of a periodic packet stream show increasing trend, once the stream rate is larger than the on the market information measure. The conclusion that found from this analysis is obtainable information measure measurements may be useful in transport protocols, dynamic server and proxy selection, adaptive reconguration of over-lay networks, and in rate-adaptive streaming applications. [8]

2.4.4 Pathchirp: Efficient Available Bandwidth Estimation for Network Paths

This journal was written by Vinay J. Ribeiro,Rudolf H. Riedi,Richard G. Baraniuk Jiri Navratil and Les Cottrell. This Research is about Pathchirp whereby this is active probing tool for estimating the available bandwidth on a communication network path. Based on the concept of “self-induced congestion,” Pathchirp structures is an exponential flight pattern of probes that called a chirp. Packet chips offer several necessary returns over current probing schemes based on packet pairs or packet trains. By quickly increasing the probing rate within each chirp, Pathchirp acquires a rich set of information from which to dynamically estimation the available bandwidth. Since it uses only packet inter rival times for estimation, Pathchirp doesn't require synchronous nor highly stable clocks at the sender and receiver. The researcher take a look at Pathchirp with simulations and internet experiments and realize that it provides sensible estimates of the available bandwidth while using only a fraction of the number of probe bytes that current progressive techniques use. [7]

2.4.5 Summary of the research

Research	Tools	Simulation/Method/Technique
Assolo, a New Method for Available Bandwidth Estimation	Assolo	The tool runs inside a real-time operating system and uses some de-noising techniques to improve the measurement process. The tests a wide range of rates being more accurate in the center of the probing interval
Comparative Analysis of Active Bandwidth Estimation Tools	Cprobe IGI/PTR NetDyn pathChrip Pathload	A comparative analysis of state-of-the-art active probing tools for bandwidth estimation that the measurement techniques for different metrics and techniques is outlined, ignoring implementation details of tools
Pathchirp : Efficient Available Bandwidth Estimation for Network Paths	pathChrip	The concept is “self-induced congestion,” Pathchirp structures is an exponential flight pattern of probes that called a chirp. Packet chips offer several important returns over current probing schemes based on packet pairs or packet trains
Pathload: A measurement tool for end-to-end available bandwidth	Pathload	Pathload is that the one-way delays of a periodic packet stream show increasing trend, when the stream rate is larger than the available bandwidth
This Paper research	Assolo IGI/PTR pathChrip Pathload	Comparing the several tools in different type of environment and wireless architecture. A comparative analysis will be carried out for the attributes that consist of accuracy, failure patterns and Consistency of measurement

Table 4: Key Summary of other research and this paper

Chapter 3

RESEARCH METHODOLOGY

3.0 Introduction

The system of collecting data for research projects is known as research methodology. Research methodology also known as science of studying that how research is done scientifically either in techniques, methods and procedures needed in carried out the research. This chapter will be defining the important items in research methodology including research system architecture; the tested variables, hardware, software as well as related instrumentation will be identified. To ensure the objectives of this research is achieved and the research methodology is on the right path, few steps have been identified as a guideline. The respective phases are as follows:

I. Initiations of information gathering to kick start the research.
II. Planning of component and system architecture. Assembly of all necessary hardware and software and proceed with the development of testing procedure model.
III. Design, installation and configuration of all the required hardware and software which are required in conducting the testing of the available bandwidth estimation tools on the Wireless environment.
IV. Performed the testing based on the predefined procedure model. Conducted the bandwidth estimation over wireless network.
V. Gathered the data from respective experiment and analyzed the data from findings.

INFORMATION GATHERING

PRELIMINARY STUDY PHASE	
PRELIMINARY STUDY	Offline: Books, Journals, Thesis Projects, Research Papers,
	Online: Articles, Journals, Proceeding materials

↓

PLANNING AND INDETIFYING HARDWARE AND SOFTWARE TOOLS

RESEARCH PLANNING PHASE	
HARDWARE	Wireless Access Point
	Laptop – Sender
	Laptop – Receiver
SOFTWARE TOOLS	Bandwidth estimation tools :- Pathchirp, Pathload, Assolo and IGI/PTR
TESTING PROCEDURE	

↓

HARDWARE SETUP, SOFTWARE CONFIGURATION AND EXPERIMANT DESIGN

ARCHITECTURE DESIGN PHASE	
INSTALLATION	Hardware and software tools
SETTINGS AND CONFIGURATIONS	Access point, sender and receiver node
ENVIRONMENT	Open and Control Environment
ARCHITECTURE	• One wireless access point • Two wireless access point with same transmission rate • Wireless access point with high transmission rate at bridging • Wireless access point with low transmission rate at bridging

↓

IMPLEMENTAION AND EXPERIMENTATION

TESTING PHASE
Ran tools :- Pathchirp, Pathload, Assolo and IGI/PTR to measure, estimate and obtain the readings of the available bandwidth

↓

DATA ANALYSIS

DATA ANALYSIS PHASE
Accuracy, Failure Pattern and Consistency of measurement Analysis:- Pathchirp, Pathload, Assolo and IGI/PTR

Table 5: Methodology of this research

3.1 Overview of Research Methods

In order to complete this research project, five main phases have been defined to be used. The methodology of this research is as per layout in Figure and was performed step by step accordingly. In brief the phases that were used areas follow:-

i. Preliminary Study Phase
ii. Research Planning Phase
iii. Architecture Design Phase
iv. Testing Phase
v. Data Analysis Phase

3.1.1 Preliminary Study Phase

The first step is to perform a preliminary study about the research subject which involves searching for the right and appropriate information that are related to the problem statement. This is to ensure that this research project will be on the right path. In addition, the research methodology, research questions and problem statements becomes the guideline in planning and extracting the right information. Multiple resources such as articles, journals, books, white papers and case studies were used in the preliminary study phase to gather sufficient information. Also, best practices, recommendations, bandwidth estimation tools used and limitations of interrelated research projects that have been done will be taken into concerns and executed to ensure this research project is up to date and in accordance to the correct standards.

3.1.2 Research Planning Phase

The second phase will be the research planning phase. In order for a research project to be carried out successfully, the research project has to be planned carefully. In this phase, the steps and activities that need to be carried out will be defined and planned accordingly. This phase will ensure that the defined steps and activities will guide the flow of this research project in order to obtain the required data for analysis at a later stage in this research project. The necessary hardware and bandwidth estimation tools needed for the research project to be carried out is defined in this phase. The selected hardware needed was identified for the experimental setup. Two laptops were needed, one to act as the sender of packet and the other one as the receiver and two wireless access point in order to be the bridge to connect the two laptops for the communication to take place. The bandwidth estimation tools that will be used is defined and selected during this phase. The tools that have been selected are Pathchirp, Pathload, Assolo and IGI/PTR whereby this all tools are defined as active tool. In addition, the testing steps and procedure needs to be defined clearly so that the objectives of this research project will be achieved. Scope limitation of this research project is also defined during this phase.

Tool	**Mode**	**Description**
Assolo	Active Only	Active probing tool for estimating available bandwidth based on the concept of "self-induced congestion"
IGI/PTR	Active Only	This is an end-to-end available bandwidth measurement tool that uses active packet-train probing
Pathchrip	Active & Passive	This is an active probing tool for estimating the available bandwidth on a communication network path.

Table 6: Summary of tools used

3.1.3 Architecture Design Phase

In this phase, the assembly, installation & configuration of the hardware and bandwidth estimation tool is executed to provide the complete test bed in the wireless environment to perform the testing of the bandwidth estimation tools in order to obtain the data readings for analysis at a later phase. The activities that are involved in this phase include:

i. Two laptops were set up
ii. Linksys E1200 wireless access point
iii. Optimum and Network with External Traffic
iv. Three type of architecture.

3.1.4 Testing Phase

Once the design has been done, the data collection will be done under this phase which is the testing phase. The selected and pre-defined tools will be run to obtain the measurement of the bandwidth as the data to be analyzed in the next phase. The data will be collect based on table below that consist eight testing.

< Type of environment> - Architecture																					
Tools	Reading of bandwidth																				Mean

Table 7: Sample of testing table that will be used in this experimental project

3.1.5 Data Analysis Phase

Data analysis phase is the phase where the data's are obtained and collected. The data that was collected is important towards this research project as they will be interpreted and analyzed to answer the research objectives, research questions and problem statements. A comparative analysis will be carried out for the attributes that consist of accuracy, failure patterns and Consistency of measurement Conclusion of this research project is derived from the data analysis phase.

3.2 Gantt Chart

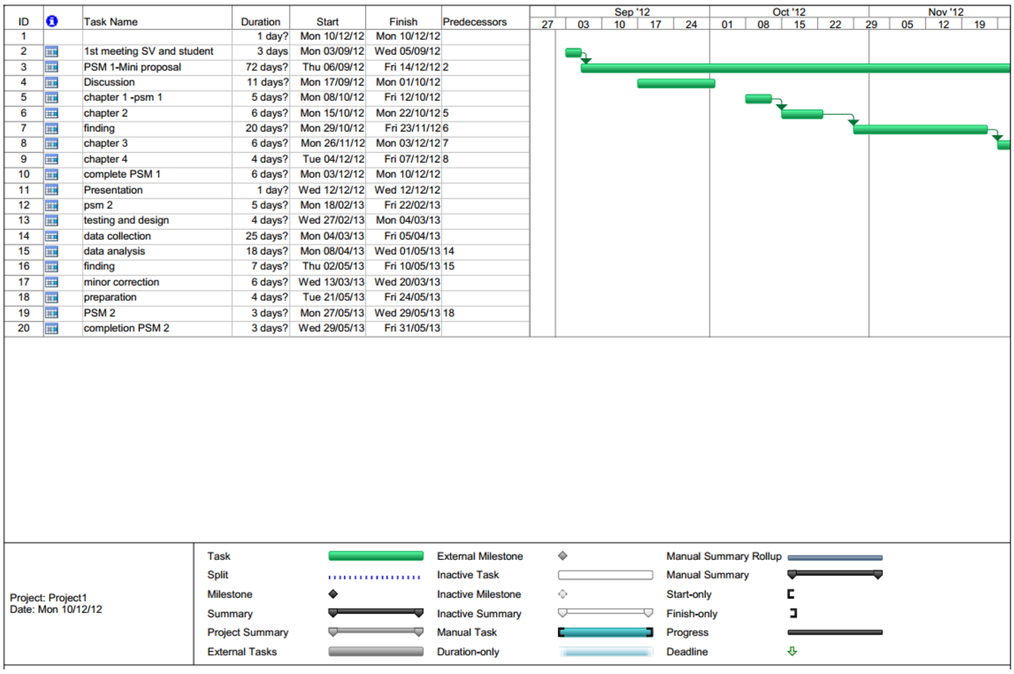


Figure 6: Gantt chart for this project

Chapter 4

DESIGN IMPLEMENTATION AND RESULT

4.0 Introduction

This research project was carried out based on the objectives of this research project that has been defined. It is crucial to state the step-by-step procedure in detail to ensure that this research project is on the right course and that the defined procedure of methodology always coincides with the objectives of this research project. The experimental setup was made to provide a wireless local area network 802.11g standard platform for two laptops to communicate where one of them will be the sender while the other will be the receiver in order to estimate the end-to-end available bandwidth. Based on the methodology in design phase, it is important to ensure that the hardware and software tools used will be able to perform and carry out the task of obtaining the required data.

4.1 Experimental Environment Design

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. This activities involve :

I. Two laptops were set up, one for sender and one for receiver. Each laptop will be installed and configured with the bandwidth estimation tool. Example like Assolo, IGI-PTR and pathChrip.

II. Wireless access point (AP) – set up the wireless AP with the default setting for the wireless communication to take place between sender and the receiver. It is to ensure the communication between sender and receiver can be performed.

III. Wireless network environment consists of optimum network whereby network without external traffic and network with external traffic that consists of ongoing FTP session - The experiment will be conduct on 2 type of environment and each of tool will be test on each of the environment.

IV. Wireless network bandwidth. The bandwidth will be set at different transmission rate to look at the effect on the tools. The setup involves changing of transmission rate in between the bridging Aps. Basically, three types of architecture involve:

1. One wireless Access Point
2. Two wireless with same transmission rate
3. Two access point with variable transmission rate (higher rate between bridging Aps)

4.2 Experiment architecture and result

Once the design has been done, the data collection will be done under this phase which is the testing phase. The selected and pre-defined tools will be run to obtain the measurement of the bandwidth as the data to be analyzed in the next phase. The data will be collect based on table below that consist eight testing. There is 2 type of architecture for two wireless access point that consist of same transmission rate for all nodes and high transmission rate at bridging

4.2.1 Optimum network (without external traffic)

a. One wireless access point with two Laptop with

The experimental setup was made to provide a wireless local area network 802.11b/g standard platform for two laptops to communicate where one of them will be the sender while the other will be the receiver in order to estimate the end-to-end available bandwidth. Based on the methodology in design phase, it is important to ensure that the hardware and software tools used will be able to perform and carry out the task of obtaining the required data. As in Figure 5, there is one access point is present and two laptops are connected to test the software. Laptop A and B is connected to the same Access point. The network was setup without any other traffic.

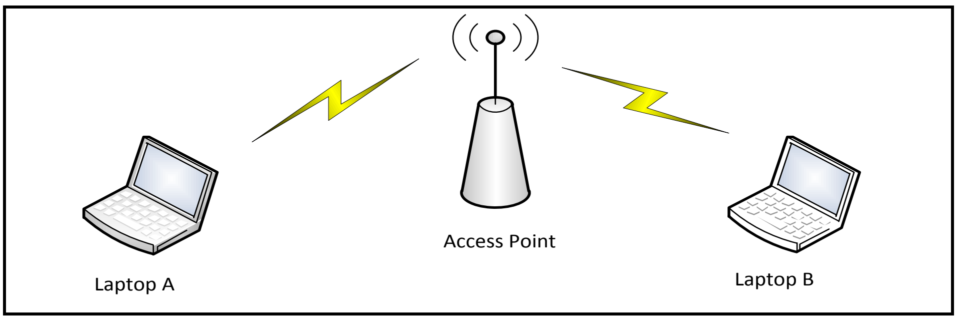
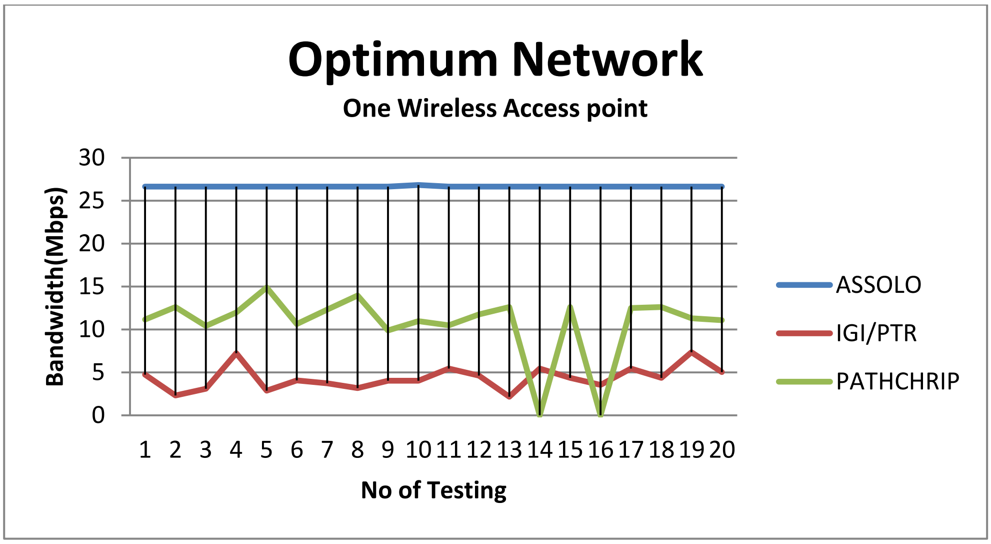


Figure 7: Design of one wireless access point with optimum network

Tools	Mean
Assolo	**26.6387**
IGI-PTR	**4.3385**
Pathchirp	**10.6728**

Table 8: The mean result of the testing for this design



Graph 1: 20 Reading of optimum network with one wireless access point.

b. Two wireless access point with two Laptop. (Same transmission rate)

This platform for two laptops to communicate where one of them will be the sender while the other will be the receiver in order to estimate the end-to-end available bandwidth. Based on the methodology in design phase, it is important to ensure that the hardware and software tools used will be able to perform and carry out the task of obtaining the required data. As in Figure 6, there is two access point is present and two laptops are connected to test the software. The bandwidth is set all the same as shown below. The bridging concept is use to make sure laptop A and Laptop B can connected each other. The network was setup without any other traffic.

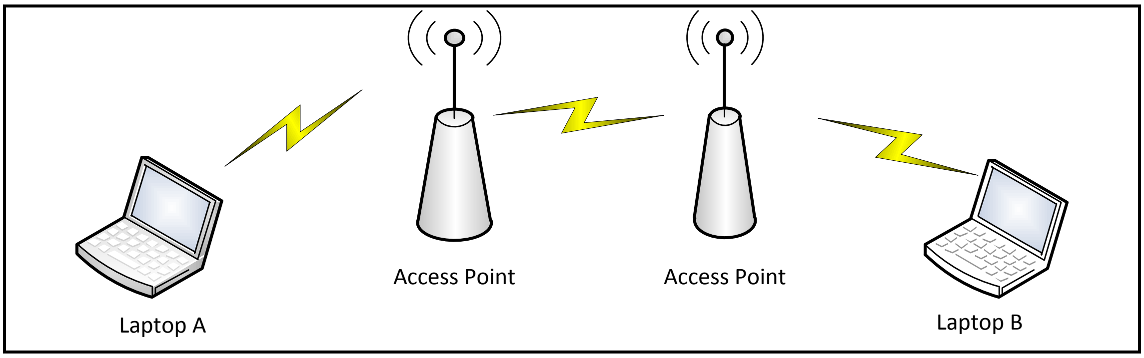
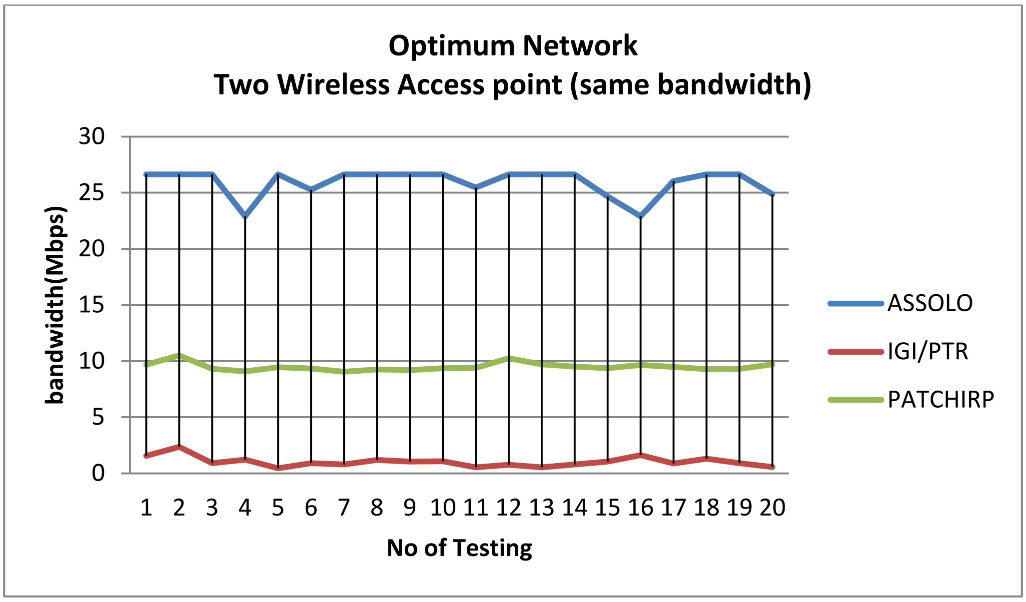


Figure 8: Design for two wireless access point with same transmission rate

Tools	**Mean**
Assolo	25.9690
IGI-PTR	1.0157
Pathchirp	9.4870

Table 9: The mean result of the testing for this design



Graph 2: 20 Reading of Optimum Network Two Wireless Access point (same bandwidth)

c. Two wireless access point with two Laptop. (with high transmission rate at bridging)

This platform for two laptops to communicate where one of them will be the sender while the other will be the receiver in order to estimate the end-to-end available bandwidth. Based on the methodology in design phase, it is important to ensure that the hardware and software tools used will be able to perform and carry out the task of obtaining the required data. As in Figure 7, there is two access point is present and two laptops are connected to test the software. The bandwidth is set high between access point and low at nodes of the network that attach to the laptop. The bridging concept is use to make sure laptop A and Laptop B can connected each other. The network was setup without any other traffic.

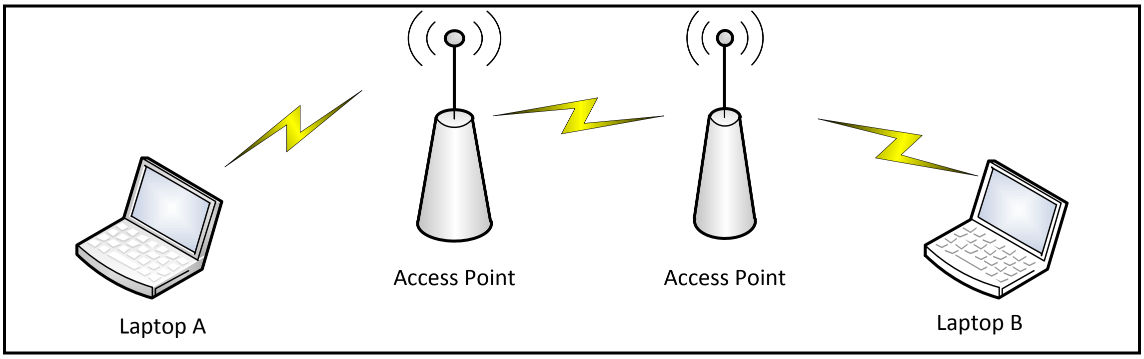
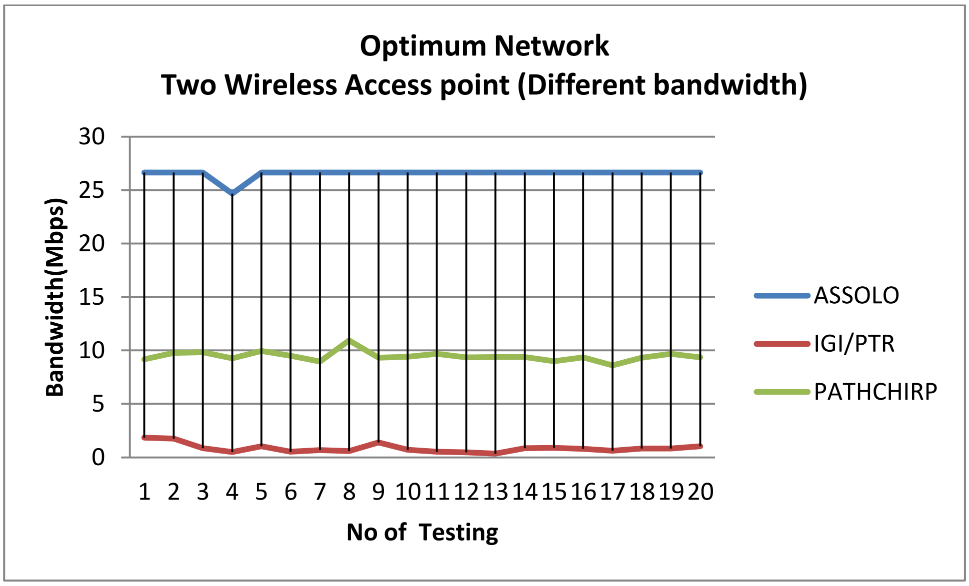


Figure 9: Design for wireless access point with high transmission rate at bridging

Tools	Mean
Assolo	**26.5307**
IGI-PTR	0.8494
Pathchirp	**9.4580**

Table 10: The mean result of the testing for this design



Graph 3: 20 Reading of Optimum Network Two Wireless Access point (different bandwidth)

4.2.2 Network with external traffic that consists of ongoing FTP session

a. One wireless access point with two Laptop with

The experimental setup was made to provide a wireless local area network 802.11b/g standard platform for two laptops to communicate where one of them will be the sender while the other will be the receiver in order to estimate the end-to-end available bandwidth. Based on the methodology in design phase, it is important to ensure that the hardware and software tools used will be able to perform and carry out the task of obtaining the required data. As in Figure 5, there is one access point is present and two laptops are connected to test the software. Laptop A and B is connected to the same Access point. The network was setup with FTP traffic that sent data from Laptop A to Laptop B

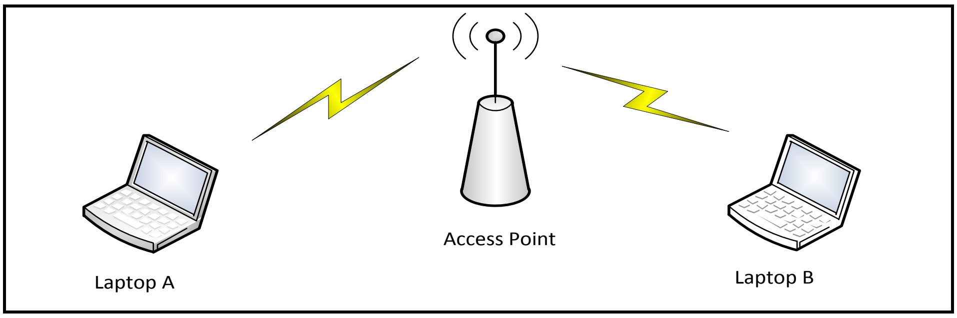
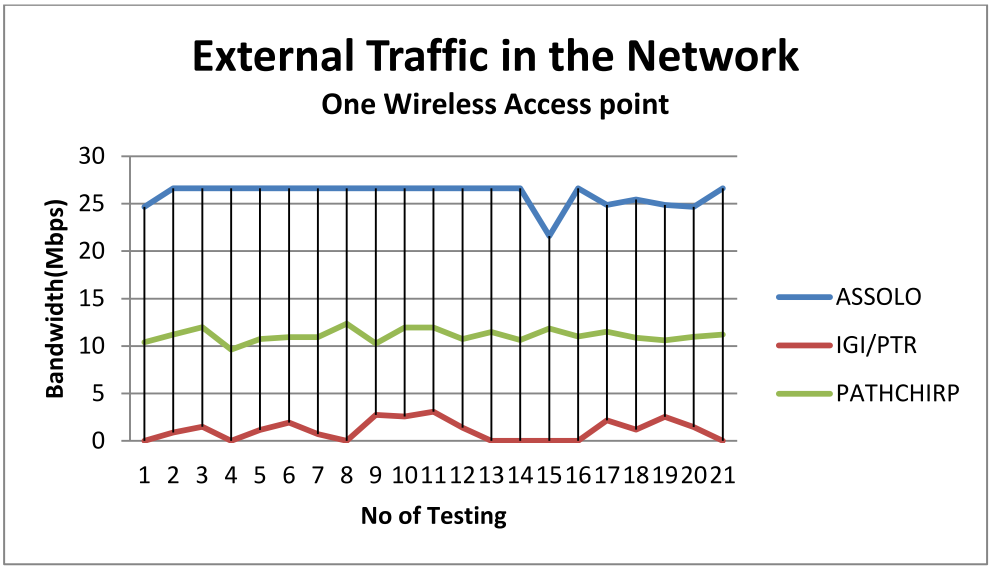


Figure 10: Design of one wireless access point with external traffic network

Tools	Mean
Assolo	**25.7492**
IGI-PTR	1.2034
Pathchirp	**11.1053**

Table 11: The mean result of the testing for this design



Graph 4: 20 reading for network that FTP session is present with one wireless access point

b. Two wireless access point with two Laptop. (same transmission rate)

This platform for two laptops to communicate where one of them will be the sender while the other will be the receiver in order to estimate the end-to-end available bandwidth. Based on the methodology in design phase, it is important to ensure that the hardware and software tools used will be able to perform and carry out the task of obtaining the required data. As in Figure 6, there is two access point is present and two laptops are connected to test the software. The bandwith is set all the same as shown below. The bridging concept is use to make sure laptop A and Laptop B can connected each other. The network was setup with FTP trafic that sent data from Laptop A to Laptop B

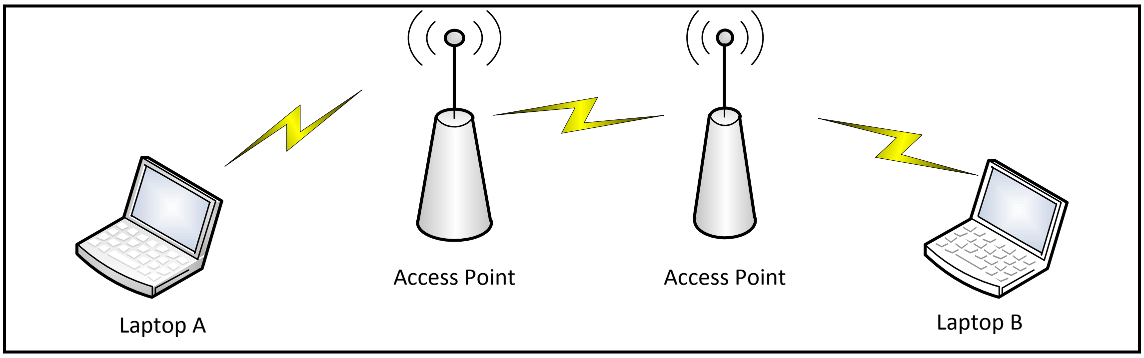
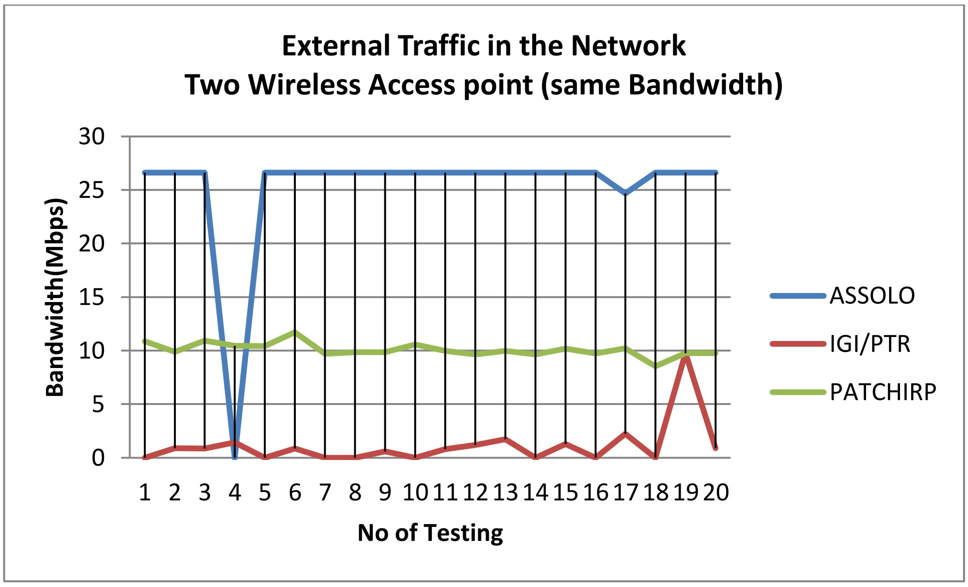


Figure 11: Design for two wireless access point with same transmission rate

Tools	Mean
Assolo	**25.1993**
IGI-PTR	1.0804
Pathchirp	**10.0844**

Table 12: The mean result of the testing for this design



Graph 5: 20 reading for network that FTP session is present with two Wireless Access point (same Bandwidth)

c. Two wireless access point with two Laptop. (with high transmission rate at bridging)

This platform for two laptops to communicate where one of them will be the sender while the other will be the receiver in order to estimate the end-to-end available bandwidth. Based on the methodology in design phase, it is important to ensure that the hardware and software tools used will be able to perform and carry out the task of obtaining the required data. As in Figure 7, there is two access point is present and two laptops are connected to test the software. The bandwith is set high betweem access point and low at nodes of the network that attach to the laptop. The bridging concept is use to make sure laptop A and Laptop B can connected each other. The network was setup with FTP trafic that sent data from Laptop A to Laptop B

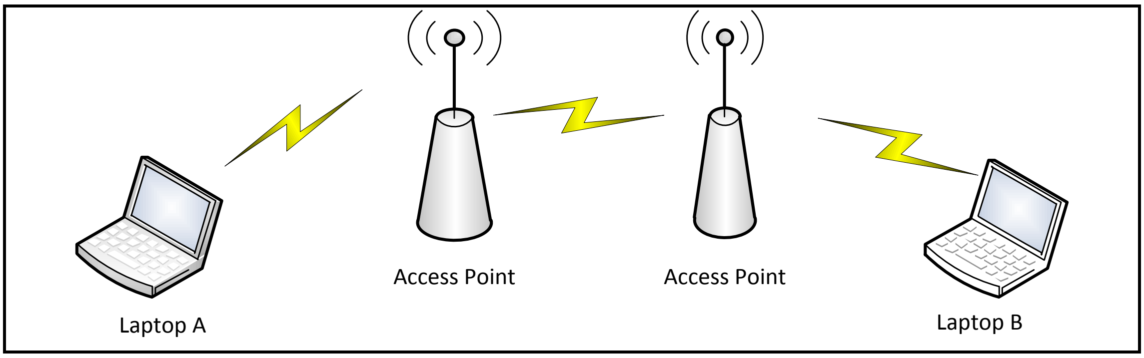
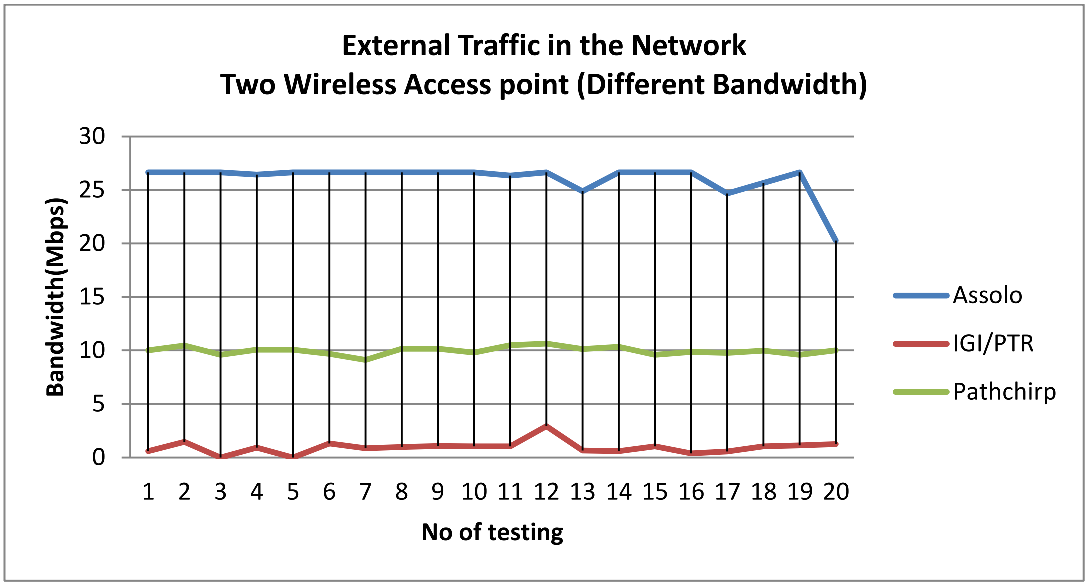


Figure 12: Design for two wireless access point with high transmission rate at bridging

Tools	Mean
Assolo	**26.5167**
IGI-PTR	0.9386
Pathchirp	**9.9738**

Table 13: The mean result of the testing for this design



Graph 6: 20 reading for network that FTP session is present with two Wireless Access point (different Bandwidth)

Chapter 5

DISCUSSION AND CONCLUSION

5.0 Introduction

The research was done to assist network administrator to select the best tool to monitor available bandwidth in the multiple wireless local area network environments. The selected tool is based on three criteria's which are accuracy, failure patterns and consistency of measurement. The experiment was done in a real time operating system that will give a better accurate compare to a simulation.

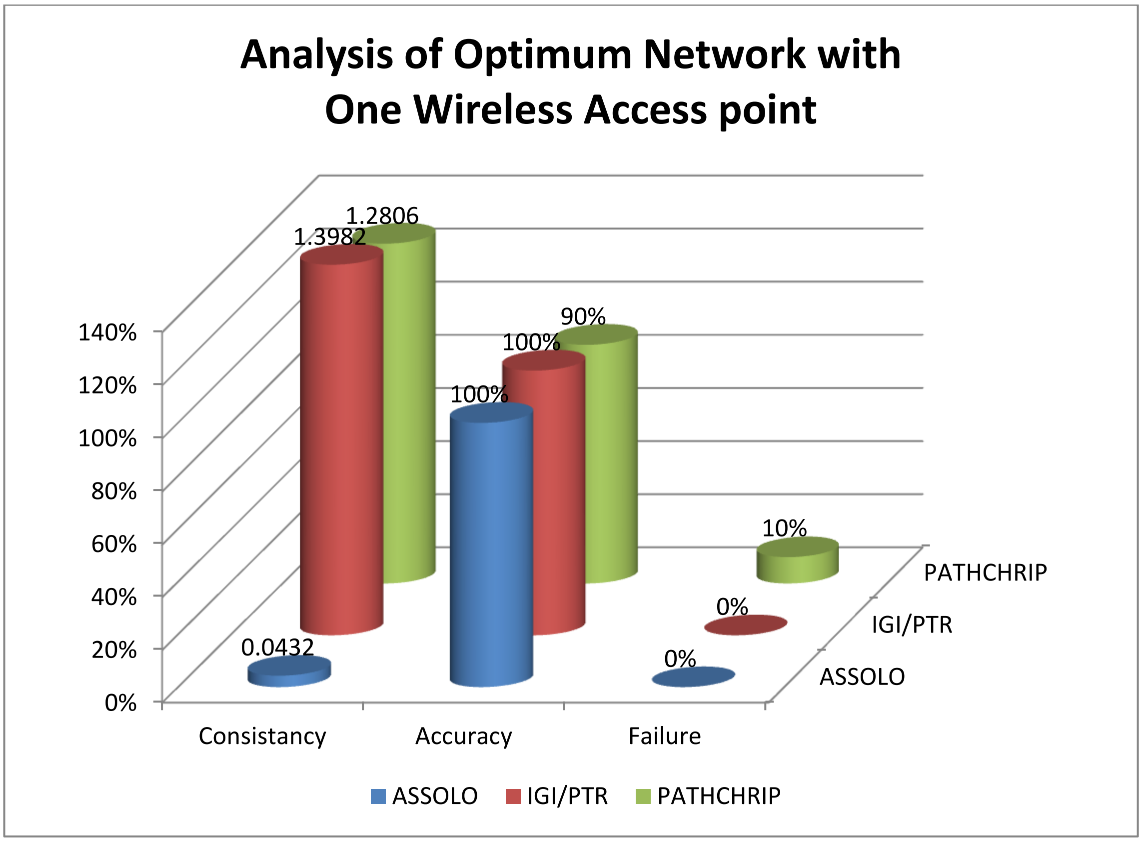
5.1 Result Analysis and Discussion

5.1.1 Optimum Network

A. One Wireless Access Point

Tools	ASSOLO	IGI/PTR	PATHCHRIP
Mean	**26.6387**	**4.3385**	**10.6728**
Consistancy	**0.0432**	**1.3982**	**1.2806**
Accuracy	**100%**	**100%**	**90%**
Failure	**0%**	**0%**	**10%**

Table 14: Summary of Optimum Network with one Wireless Access Point



Graph 7: Summary of Optimum Network with one Wireless Access Point

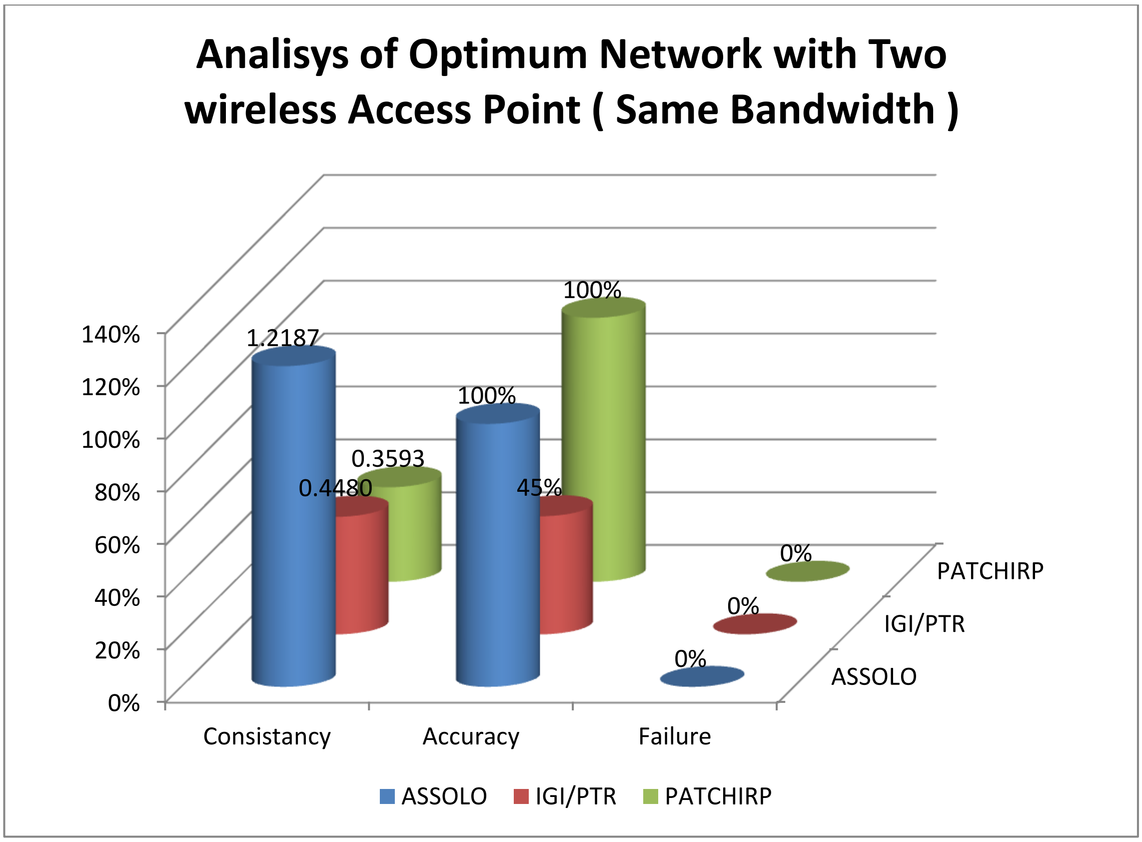
From the graph and table above, we can see that all the tools give different results. In term of consistency, the mean and standard deviation was calculated. The mean for the Assolo is 26.6387 followed by IGI_PTR was 4.3385 and Pathchirp was 10.6728. The standard deviation (SD) for Assolo was 0.0432 followed by IGI-PTR was 1.3982 and Pathchirp was 1.2086. This shows that Assolo gives the consistent reading for this type of experiment.

In term of accuracy, Assolo and IGI-PTR got 100% of the estimation readings which were in the range of the benchmark that has been set while Pathchirp was 90% accurate for this test. In term of failure pattern, Assolo and IGI-PTR managed to produce an estimated bandwidth reading for all 20 cycle test that was conducted. Therefore, both tools have a 0% failure rate. Unfortunately for Pathchip, it has a 10% of failure rate.

B. Two Wireless Access Point with Same Bandwidth

Tools	ASSOLO	IGI/PTR	PATCHIRP
Mean	**25.9116**	**1.0157**	**9.4870**
Consistancy	**1.2187**	**0.4480**	**0.3593**
Accuracy	**100%**	**45%**	**100%**
Failure	**0%**	**0%**	**0%**

Table 15: Summary of Optimum Network with two Wireless Access Point with same bandwidth



Graph 8: Summary of Optimum Network with two Wireless Access Point with same bandwidth

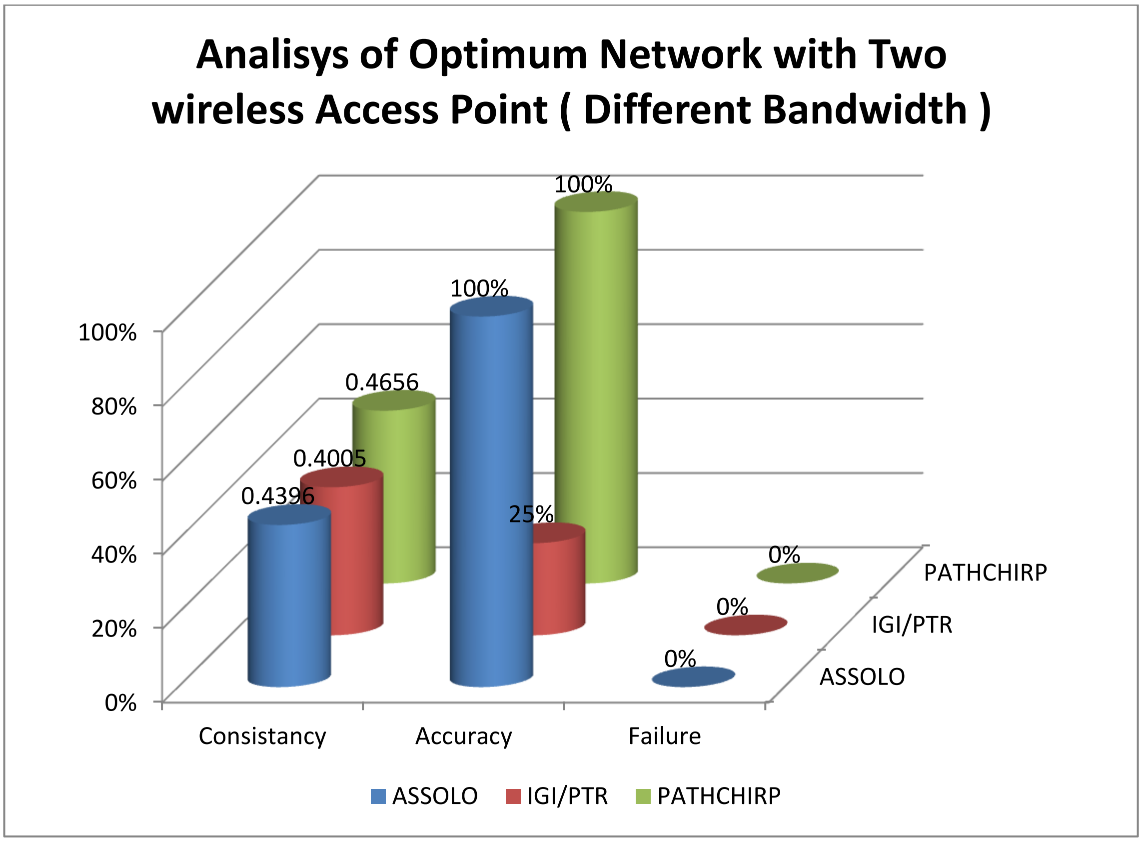
From the graph and table above, we can see that all the tools give different results. In term of consistency, the mean and standard deviation was calculated. The mean for the Assolo was 25.9116 followed by IGI_PTR was 1.0157 and Pathchirp was 9.4870. The standard deviation (SD) for Assolo was 1.2187 followed by IGI-PTR was 0.4480 and Pathchirp is 0.3593. This shows that Pathchirp gives the consistent reading for this type of experiment.

In term of accuracy, Assolo and Pathchirp got 100% of the estimation readings which was in the range of the benchmark that has been set while IGI-PTR was 45% accurate for this test. In term of failure pattern, all tools was produced all results for twenty cycles therefore; it shows that all tools was 0% of failure rate.

C. Two Wireless Access Point with Different Bandwidth

Tools	ASSOLO	IGI/PTR	PATHCHIRP
Mean	**26.5307**	**0.8494**	**9.4579**
Consistancy	**0.4396**	**0.4005**	**0.4656**
Accuracy	**100%**	**25%**	**100%**
Failure	**0%**	**0%**	**0%**

Table 16: Summary of Optimum Network with two Wireless Access Point with different bandwidth



Graph 9: Summary of Optimum Network with two Wireless Access Point with different bandwidth

From the graph and table above, we can see that all the tools give different results. In term of consistency, the mean and standard deviation was calculated. The mean for the Assolo was 26.5307 followed by IGI_PTR was 0.8494 and Pathchirp is 9.4579. The standard deviation (SD) for Assolo was 0.4396 followed by IGI-PTR was 0.4005 and Pathchirp was 0.4656. This shows that IGI-PTR gives the consistent reading for this type of experiment.

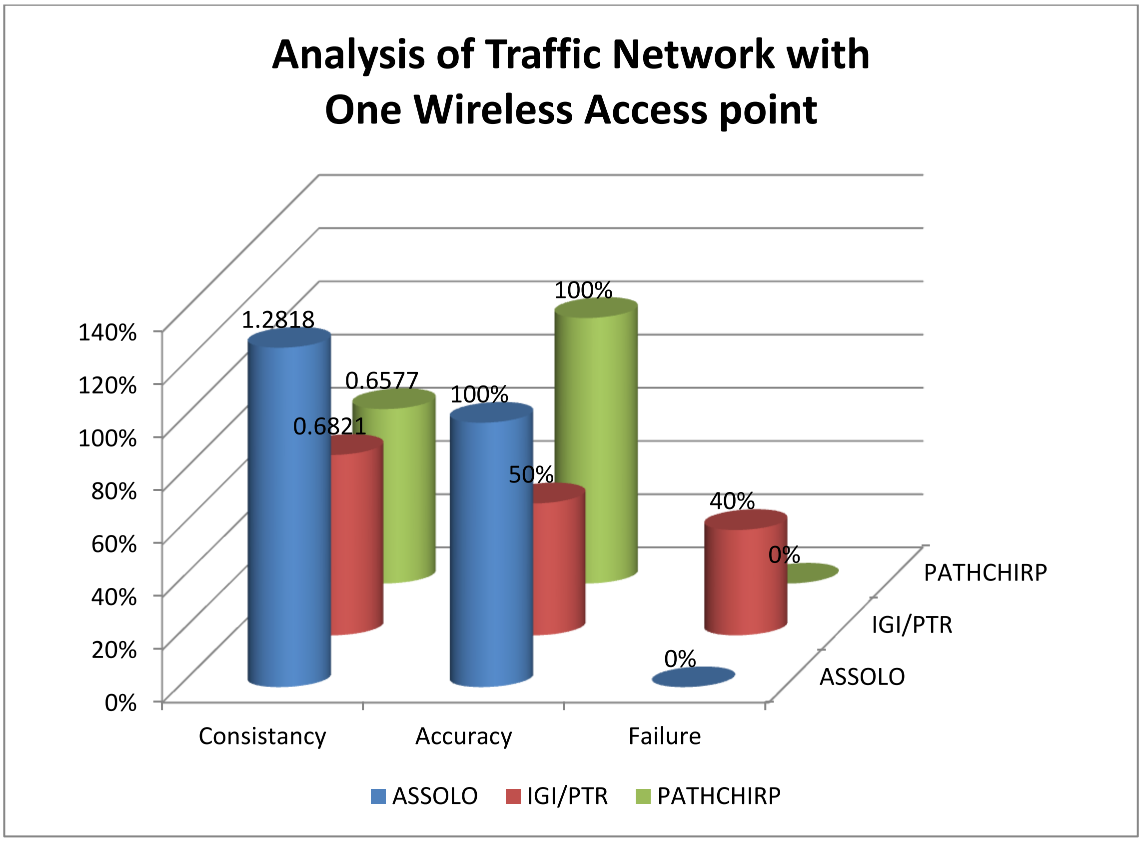
In term of accuracy, Assolo and Pathchirp got 100% of the estimation readings which was in the range of the benchmark that has been set while IGI-PTR was 25% accurate for this test. In term of failure pattern, all tools was produced all results for twenty cycles therefore; it shows that all tools was 0% of failure rate.

5.1.2 Network with External Traffic

A. One Wireless Access Point

Tools	ASSOLO	IGI/PTR	PATHCHIRP
Mean	**25.9459**	**1.0129**	**11.0625**
Consistancy	**1.2818**	**0.6821**	**0.6577**
Accuracy	**100%**	**50%**	**100%**
Failure	**0%**	**40%**	**0%**

Table 17: Summary of Traffic Network with one wireless Access Point



Graph 10: Summary of Traffic Network with one wireless Access Point

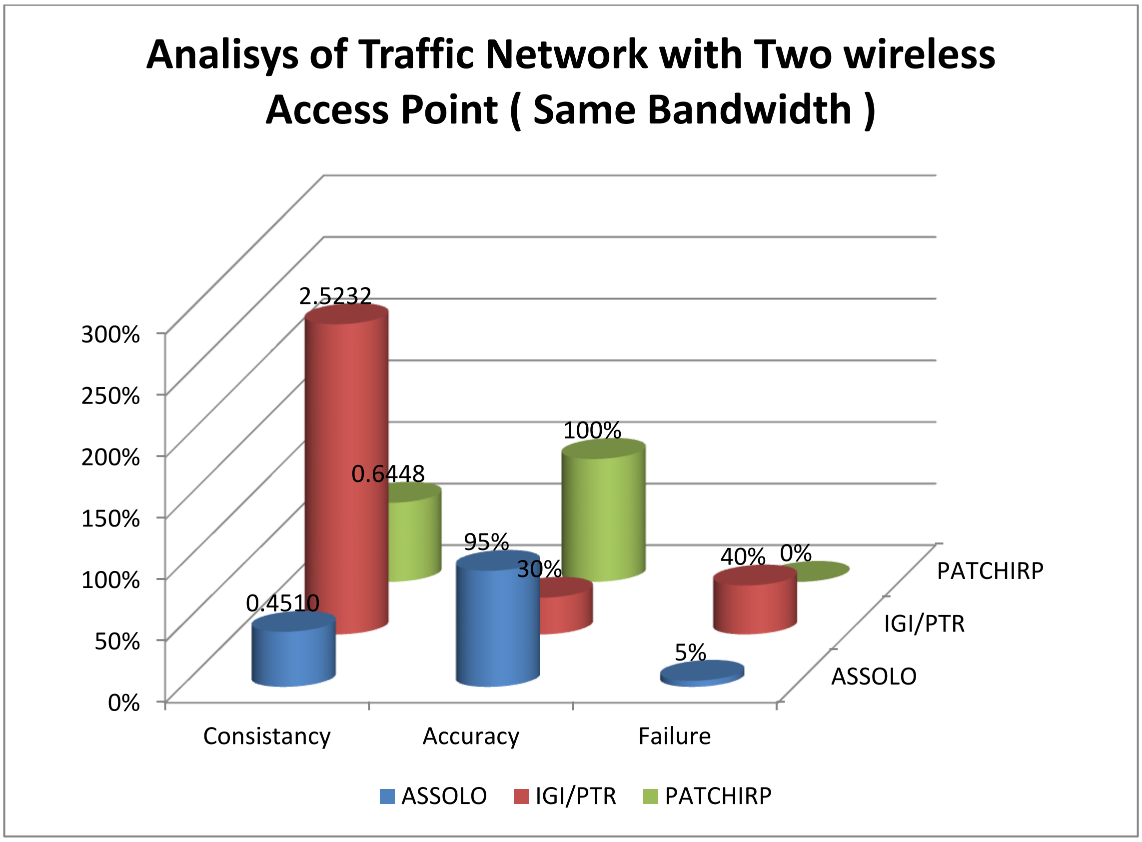
From the graph and table above, we can see that all the tools give different results. In term of consistency, the mean and standard deviation was calculated. The mean for the Assolo was 25.9459 followed by IGI_PTR was 1.0129 and Pathchirp was 11.0625. The standard deviation (SD) for Assolo was 1.2818 followed by IGI-PTR was 0.6821 and Pathchirp was 0.6577. This shows that Pathchirp gives the consistent reading for this type of experiment.

In term of accuracy, Assolo and Pathchirp got 100% of the estimation readings which was in the range of the benchmark that has been set while IGI-PTR was 50% accurate for this test. In term of failure pattern, Assolo and Pathchirp produced all results for twenty cycles therefore; it shows that Assolo and Pathchirp was 0% of failure whereby the IGI-PTR was 40% of failure rate.

B Two Wireless Access Point with Same Bandwidth

Tools	ASSOLO	IGI/PTR	PATCHIRP
Mean	**25.1993**	**1.1248**	**10.0844**
Consistancy	**0.4510**	**2.5232**	**0.6448**
Accuracy	**95%**	**30%**	**100%**
Failure	**5%**	**40%**	**0%**

Table 18: Summary of Traffic Network with two Wireless Access Point with same bandwidth



Graph 11: Summary of Traffic Network with two Wireless Access Point with same bandwidth

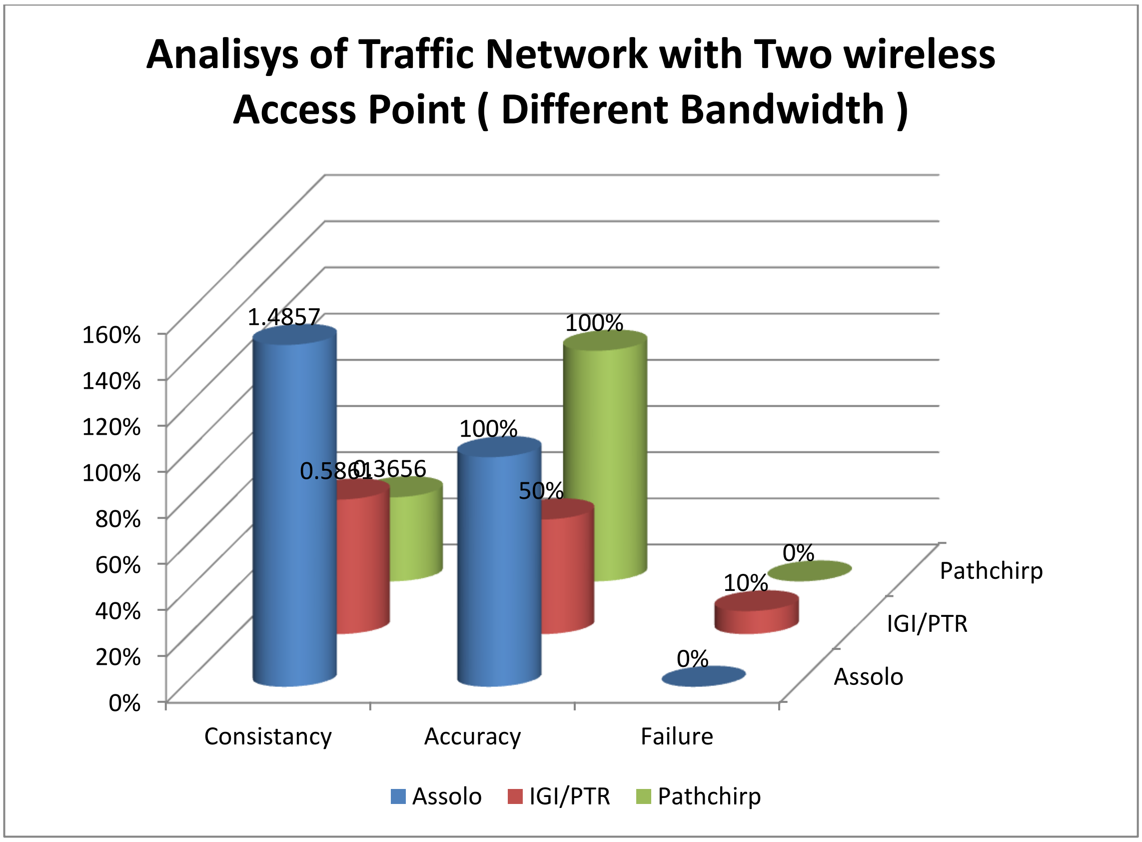
From the graph and table above, we can see that all the tools give different results. In term of consistency, the mean and standard deviation was calculated. The mean for the Assolo was 25.1993 followed by IGI_PTR was1.1248 and Pathchirp was 10.0844. The standard deviation (SD) for Assolo was 0.4510 followed by IGI-PTR was 2.5232 and Pathchirp was 0.6448. This shows that Assolo gives the consistent reading for this type of experiment.

After that, for the accuracy, Pathchirp got 100% of the estimation readings which was in the range of the benchmark that has been set while IGI-PTR was 50% and Assolo 95% of accuracy for this test. In term of failure pattern, Assolo and Pathchirp produced all results for twenty cycles therefore; it shows that Assolo and Pathchirp was 0% of failure whereby the IGI-PTR was 40% of failure rate.

C. Two Wireless Access Point with Different Bandwidth

Tools	Assolo	IGI/PTR	Pathchirp
Mean	**26.0517**	**0.9388**	**9.9738**
Consistancy	**1.4857**	**0.5861**	**0.3656**
Accuracy	**100%**	**50%**	**100%**
Failure	**0%**	**10%**	**0%**

Table 19: Summary of Traffic Network with two Wireless Access Point with different bandwidth



Graph 12: Summary of Traffic Network with two Wireless Access Point with different bandwidth

From the graph and table above, we can see that all the tools give different results. In term of consistency, the mean and standard deviation was calculated. The mean for the Assolo was 26.0517 followed by IGI_PTR was 0.9388 and Pathchirp was 9.9738. The standard deviation (SD) for Assolo was 1.4857 followed by IGI-PTR was 0.5861 and Pathchirp was 0.3656. This shows that Assolo gives the consistent reading for this type of experiment.

After that, for the accuracy, Assolo and Pathchirp got 100% of the estimation readings which was in the range of the benchmark that has been set while IGI-PTR was 50% accuracy for this test. In term of failure pattern, Assolo and Pathchirp produced all results for twenty cycles therefore; it shows that Assolo and Pathchirp was 0% of failure whereby the IGI-PTR was 10% of failure rate.

5.2 Key Point Analysis and Discussion

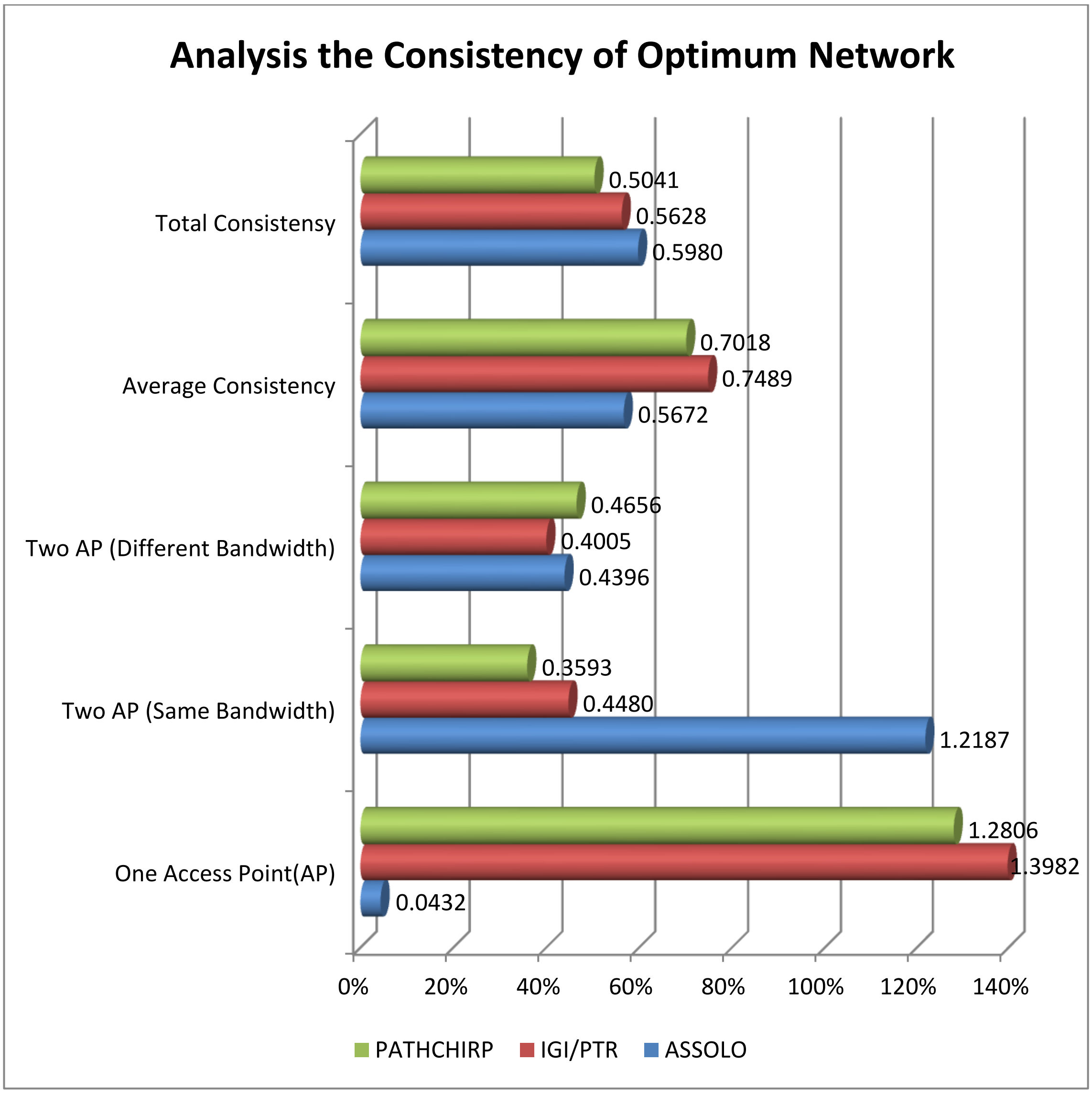
5.2.1 Consistency

The consistency of this experiment are shown at Table 1 and table 2 below , the lower the Standard Deviation (SD) shows the better consistency the data of the tool that to estimate the bandwidth. From Table 1 and 2, we can see that Assolo have lowest SD for one wireless Access Point (AP), Pathchirp at two wireless AP with same bandwidth and IGI-PTR at two wireless AP with different bandwidth for optimum network while for network with external traffic Pathchirp have the lowest SD for one wireless AP and two wireless AP with different bandwidth. This shows that Pathchirp have a good consistency of data generated from the tools for both optimum and traffic network. The total of consistency of data also shows that Pathchirp are the most suitable for both network. All tools gives consistent of reading for this experiment because all the total SD of the tools for each environment was nearest to the zero value but for best tools that researcher already choose are considered with two more key point that we will discuss later.

A. Optimum Network

Consistancy	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	**0.0432**	**1.3982**	**1.2806**
Two AP (Same Bandwidth)	**1.2187**	**0.4480**	**0.3593**
Two AP (Different Bandwidth)	**0.4396**	**0.4005**	**0.4656**
Average Consistency	0.5672	0.7489	0.7018
Total Consistensy	0.5980	0.5628	0.5041

Table 20: Summary of Consistency of Optimum Network

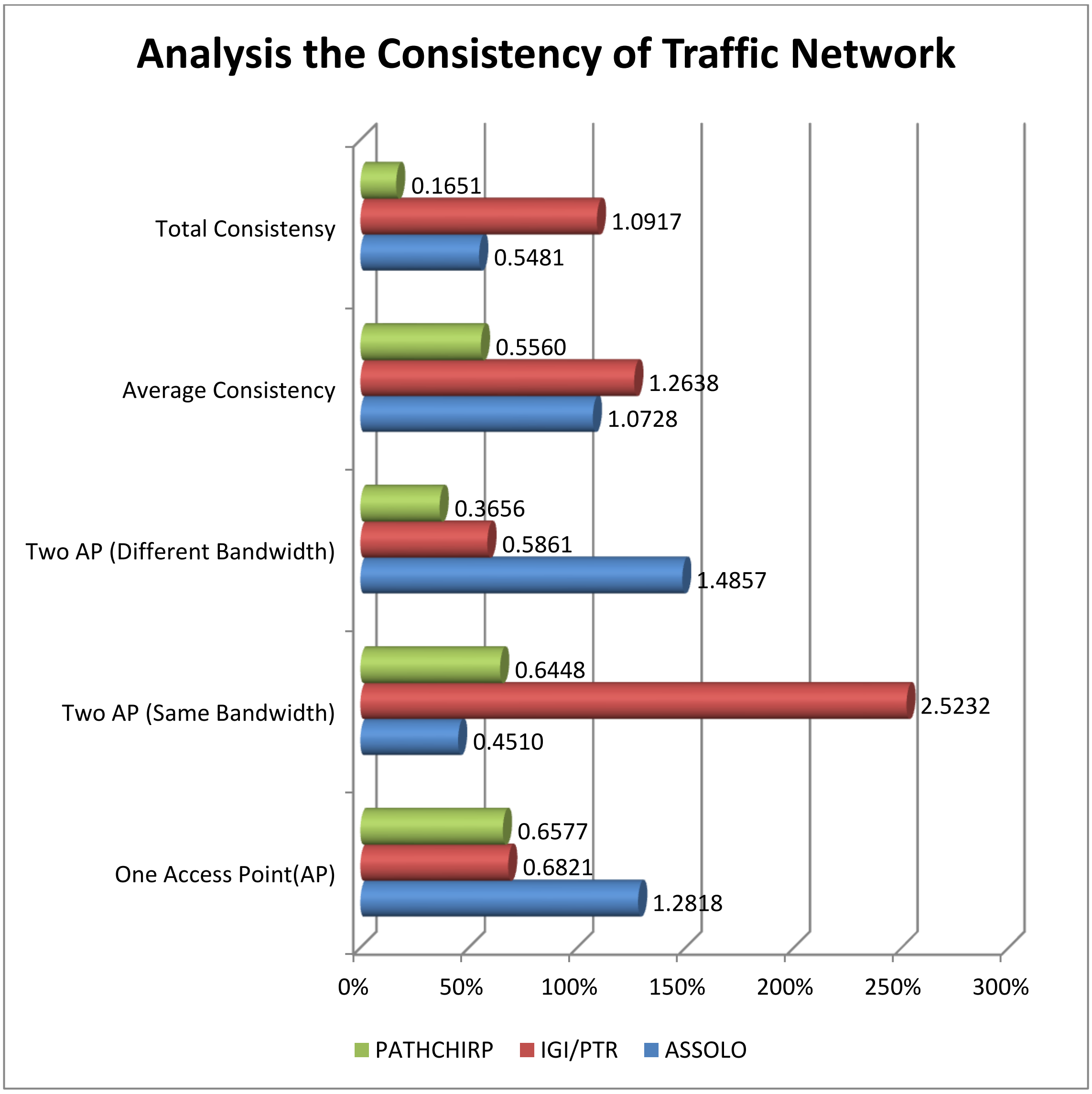


Graph 13: Summary of Consistency of Optimum Network

B. Network with Traffic

Consistancy	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	**1.2818**	**0.6821**	**0.6577**
Two AP (Same Bandwidth)	**0.4510**	**2.5232**	**0.6448**
Two AP (Different Bandwidth)	**1.4857**	**0.5861**	**0.3656**
Average Consistency	1.0728	1.2638	0.5560
Total Consistensy	0.5481	1.0917	0.1651

Table 21: Summary of Consistency of Traffic Network



Graph 14: Summary of Consistency of Traffic Network

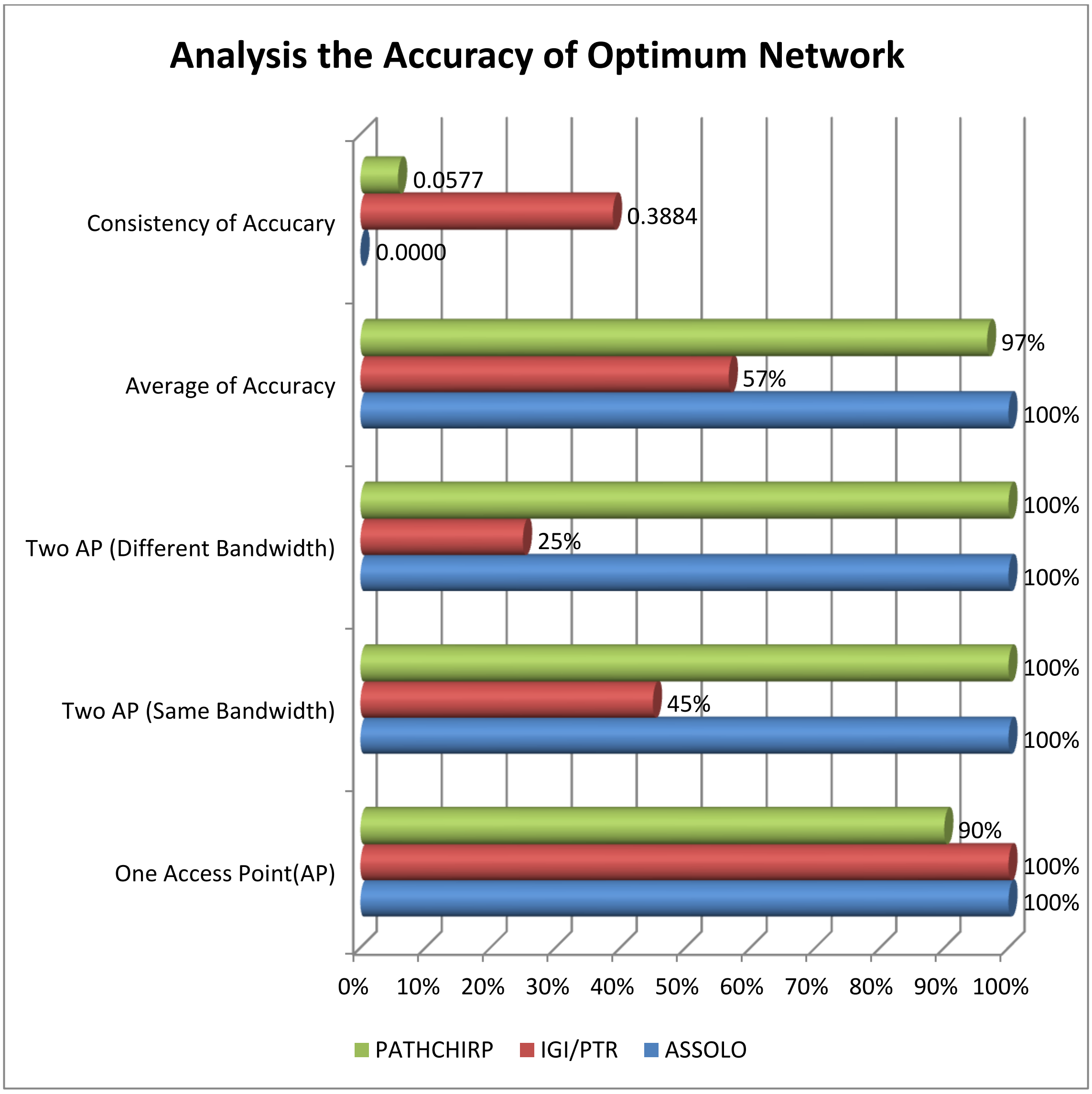
5.2.2 Accuracy

The Accuracy of this experiment are shown at Table 1 and table 2 below , the highest the percentage shows the better accuracy the data of the tool that to estimate the bandwidth. The accuracy of the data is calculated based on benchmark that state by researcher for this experiment. From Table 1 and table 2, we can see that Assolo have 100% of accuracy at optimum network while for network with external traffic Pathchirp have 100% of accuracy. This shows that both Assolo and Pathchirp have a good accuracy of data at optimum and traffic network. This is occurred because Assolo and Pathchirp was generate that data in between the benchmark that state for this experiment. This accuracy also related to the failure rate that we will discuss later. The benchmark that researcher determined for this experiment is 1 Mbps until 30 Mbps event though the maximum bandwidth for 802.11g is 54Mbps, the researcher are considering the Signal to Noise Rate (SNR), distance of client to AP and the interference of other signal. Assolo was the accurate for optimum network because Assolo can handle the packet that probe if there is no other packet intercepted it but Pathchirp was the most accurate because the probe can handle bandwidth calculation of experiment while other packet of traffic in the network itself. This was occur because Pathchirp packet more smaller than Assolo then the packet cannot be compromise by other packet in the network.

A. Optimum Network

Accuracy	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	**100%**	**100%**	**90%**
Two AP (Same Bandwidth)	**100%**	**45%**	**100%**
Two AP (Different Bandwidth)	**100%**	**25%**	**100%**
Average of Accuracy	100%	57%	97%
Consistency of Accucary	0.0000	0.3884	0.0577

Table 22: Summary of Accuracy of Optimum Network

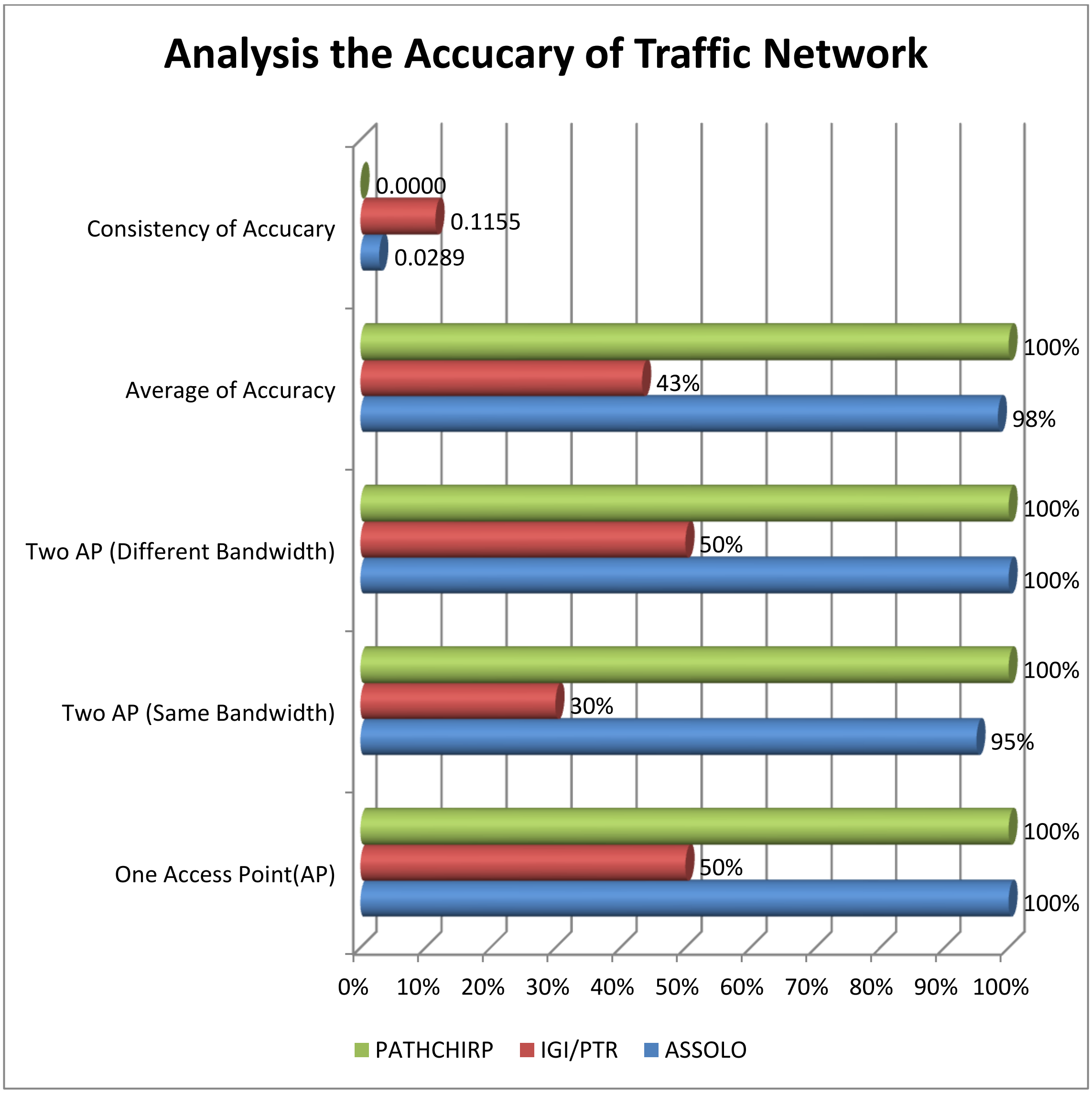


Graph 15: Summary of Accuracy of Optimum Network

B. Network with Traffic

Accuracy	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	**100%**	**50%**	**100%**
Two AP (Same Bandwidth)	**95%**	**30%**	**100%**
Two AP (Different Bandwidth)	**100%**	**50%**	**100%**
Average of Accuracy	98%	43%	100%
Consistency of Accucary	0.0289	0.1155	0.0000

Table 23: Summary of Accuracy of Traffic Network



Graph 16: Summary of Accucary of Traffic Network

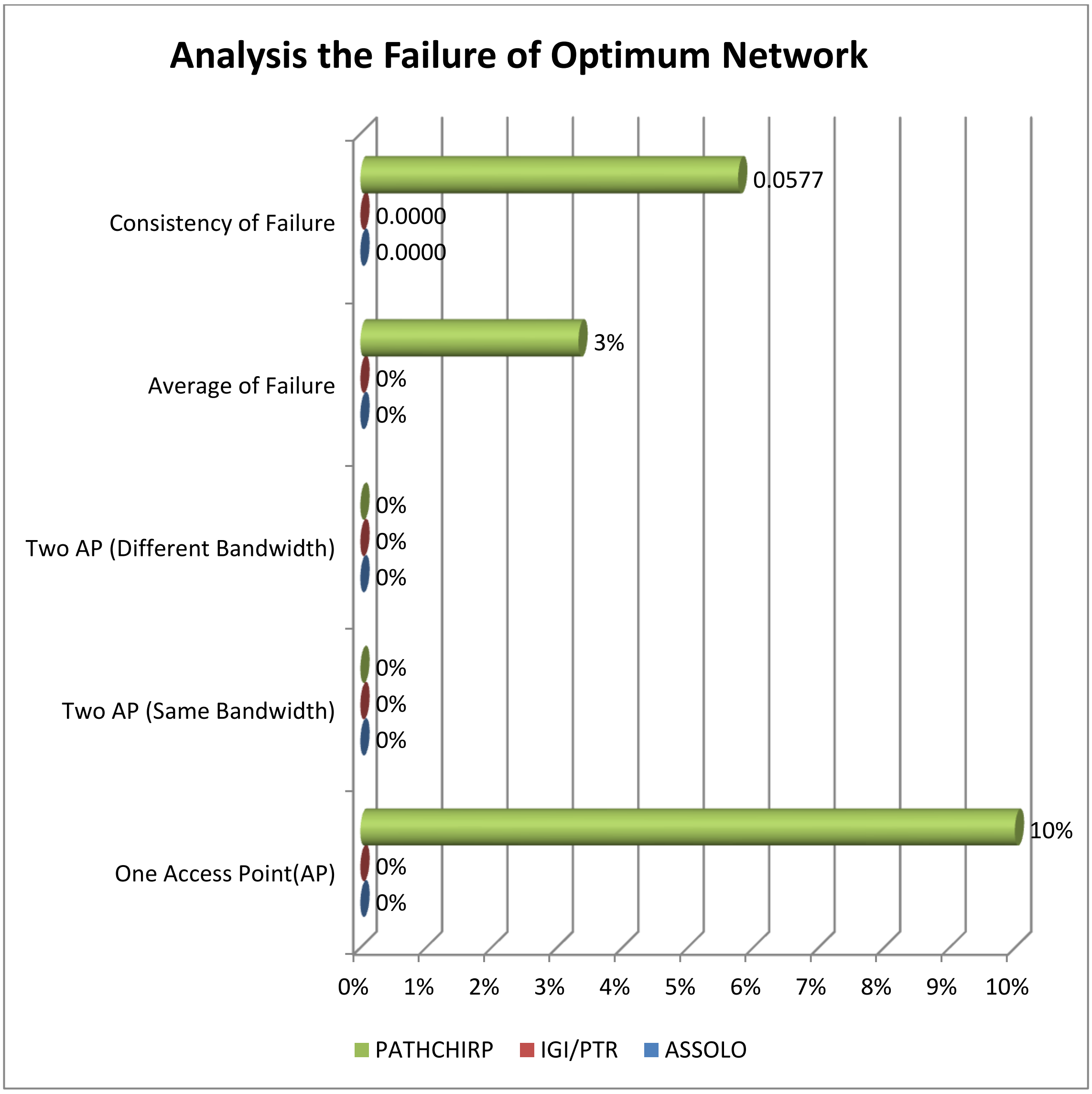
5.2.3 Failure Pattern

Table 1 and 2 shows the percentage failure of the tools.0% indicates that the tool has no failure in estimating the bandwidth which is preferred. From the table below, we can see that Pathchirp and IGI-PTR had the highest percentage of failure for optimum and traffic network. The reason to this could be that Pathchirp and IGI-PTR discards estimates when packet losses occur to avoid errors in estimation computation. However, too many packet losses would lead to failure in estimating the bandwidth. Also, Pathcirp rely on delay changes to measure the available bandwidth and when the delay is too high, it also contributes to the failure in estimating the bandwidth. The failure of estimating the bandwidth also can contributes to the accuracy of the data generate as state above. Assolo and Pathchirp have the good tools rate in term of failure rate because it can handle the packet lost to the network. This is happen because both are focusing in the packet that sent and receive to the experiment. While IGI-PTR have high rate of failure because IGI-PTR was collect 2 reading of probe in the same time. This need the tools cannot be compromise by other packet to done the experiment.

A. Optimum Network

Failure	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	**0%**	**0%**	**10%**
Two AP (Same Bandwidth)	**0%**	**0%**	**0%**
Two AP (Different Bandwidth)	**0%**	**0%**	**0%**
Average of Failure	0%	0%	3%
Consistency of Failure	0.0000	0.0000	0.0577

Table 24: Summary of Failure Rate of Optimum Network

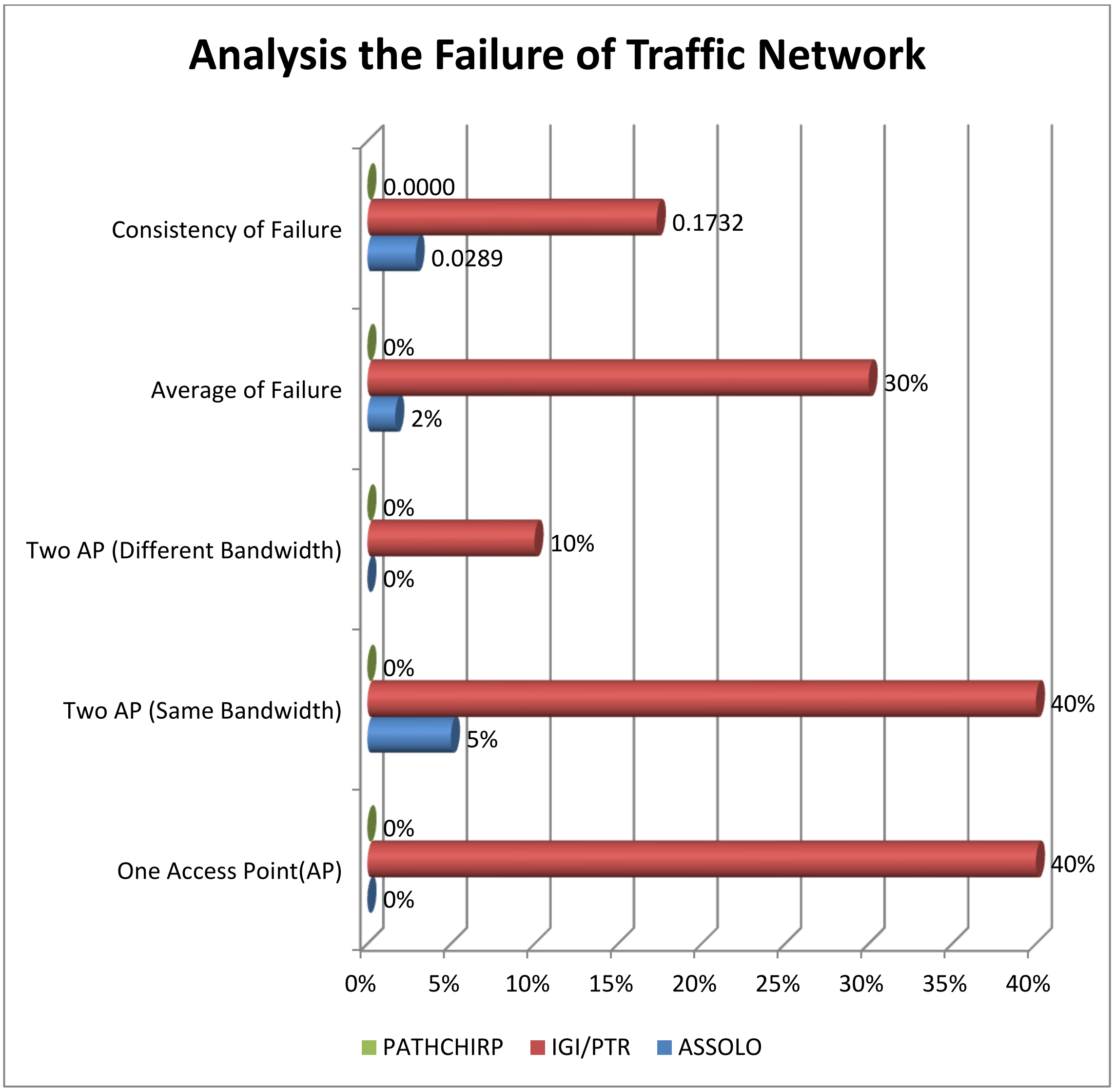


Graph 17: Summary of Failure Rate of Optimum Network

B. Network with Traffic

Failure	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	**0%**	**40%**	**0%**
Two AP (Same Bandwidth)	**5%**	**40%**	**0%**
Two AP (Different Bandwidth)	**0%**	**10%**	**0%**
Average of Failure	2%	30%	0%
Consistency of Failure	0.0289	0.1732	0.0000

Table 25: Summary of Failure Rate of Traffic Network



Graph 18: Summary of Failure Rate of Traffic Network

5.3 Summary of experimental.

Six experiments were conducted earlier covering the tools Assolo, IGI-PTR and Pathchirp that consist two environments whereby optimum network and network with external traffic. Three attributes were assessed namely accuracy, failure patterns and consistency. The experiment was conducted under the wireless 802.11g environment. For the accuracy test, a benchmark has been selected which was in the range of 1-30 Mbps based on an experimental study for the achievable bandwidth under wireless 802.11g environment [3]. Failure pattern test observes the tool's tendency to fail in measuring the available bandwidth under the 802.11g wireless environment. For the consistency test, the standard deviation formula is applied onto the estimation results that were obtain to measure the consistency of the tool's estimation in the 20 cycles conducted.

Based on the findings and analysis, in terms of accuracy in estimation, Assolo had the best results compared to the other tools in estimating the bandwidth under the wireless 802.11g standard environment at optimum network while Pathchirp is the best tools compared others for network with external traffic. For the failure pattern, IGI-PTR had the highest percentage of failure in estimating the bandwidth for traffic network and Pathchirp for optimum network. For the consistency in estimating the bandwidth, Pathchirp had the lowest value of standard deviation that make this tools is the most consistent in generating the data.

Environments	Optimum Network	Traffic Network
One Wireless Access point	Assolo	Pathchirp
Two Wireless Access point with same Transmission rate at bridging	Pathchirp	Pathchirp
Two Wireless Access point with high transmission rate at bridging	Assolo	Pathchirp

Table 26: summary of recommendation of tools for each environment and type of network

5.4 Recommendations

As defined in the Chapter 1 of this research project, there are a few limitations concerning with this research project. By considering the scopes and outcomes of the results as well as the limitations of this research project, the following proposals are recommended for future works that are related to estimating available and capacity bandwidth under the wireless network environment. Some recommendations for future work of the research:

- ✓ Experimental activities were carried in 802.11g WLAN environment. Future work can focus on extending the experiment to another wireless network such as IEEE 802.11n, GPRS, EDGE or 3G networks.
- ✓ Various other tools can be evaluated under the 802.11g wireless LAN.
- ✓ The experiment conducted was done with two hops of wireless network. For future study, three hops of network can be applied.
- ✓ Future works can focus on implementing QOS algorithm at access point itself to further look at the effects on the bandwidth estimation tools performance by setting the bandwidth rate due to the network create.
- ✓ Future works can focus on combining the active and passive tools so that we can compare which the best tools can be used.
- ✓ Future works can focus on running the experiment in windows base platform.

Reference

1. “Wireless Local Area Network (Wlan). Intenet http://searchmobilecomputing.techtarget.com/definition/wireless-LAN [October 10, 2012]

2. “What is a wireless LAN?” internet http://kb.iu.edu/data/aick.html [October 10, 2012].

3. Azfor Aizat bin Azizan (2010). “Comparisan Anlalysis of bandwith extimation tools on 802.11G wireless local area network” [October 10. 2012]

4. Jacob Strauss, Dina Katabi and Frans Kaashoek. “A Measurement Study of Available Bandwidth Estimation Tools” [October 10, 2012]

5. "Introduction to Wi-Fi (802.11 or WiFi)", Internet: http://en.kioskea.net/contents/wifi/wifiintro.php3. [October 17, 2012]

6. Emanuele Goldoni, Giuseppe Rossi and Alberto Torelli “Assolo, a New Method for Available Bandwidth Estimation”

7. Vinay J. Ribeiro,Rudolf H. Riedi,Richard G. Baraniuk Jiri Navratil and Les Cottrell “Pathchirp: Efficient Available Bandwidth Estimation for Network Paths”

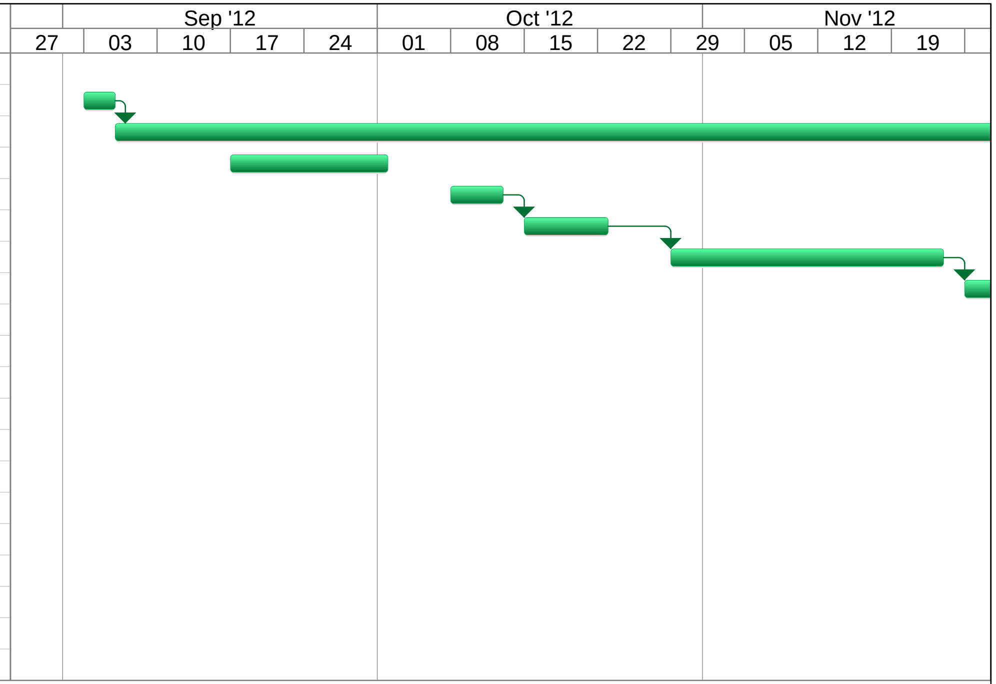
8. Manish Jain and Constantinos Dovrolis.” Pathload: A measurement tool for end-to-end available bandwidth “

9. Federico Montesino-Pouzols. “Comparative Analysis of Active Bandwidth Estimation Tools”

10. Ningning Hu and Peter Steenkiste. “Estimating A available Bandwidth Using Packet Pair Probing”

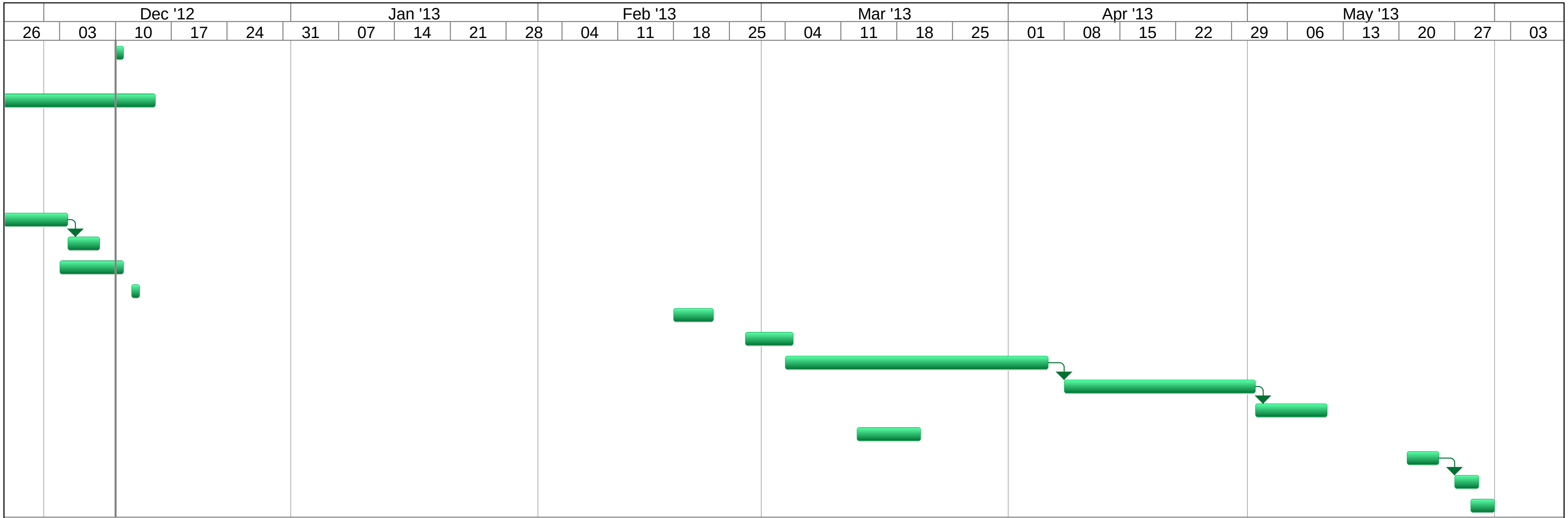
APPENDIX

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	

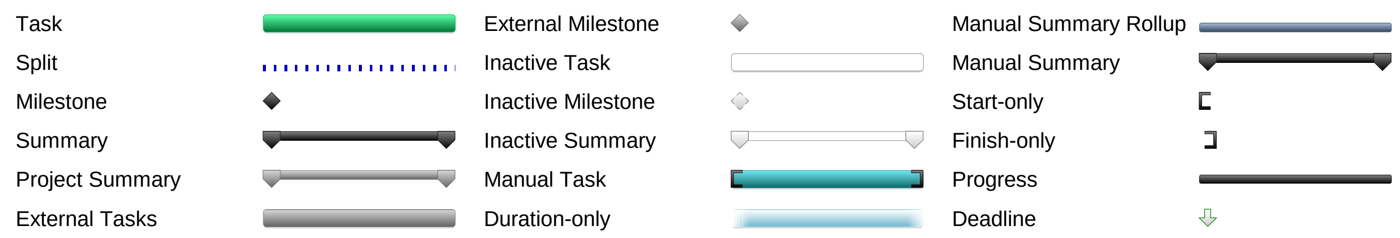


Project: Project1
Date: Mon 10/12/12

Task	External Milestone	Manual Summary Rollup
Split	Inactive Task	Manual Summary
Milestone	Inactive Milestone	Start-only
Summary	Inactive Summary	Finish-only
Project Summary	Manual Task	Progress
External Tasks	Duration-only	Deadline



Project: Project1
Date: Mon 10/12/12



Jun '13				Jul '13				Aug '13					Sep '13				Oct '13					Nov '13				De	
03	10	17	24	01	08	15	22	29	05	12	19	26	02	09	16	23	30	07	14	21	28	04	11	18	25	02	09

Project: Project1
Date: Mon 10/12/12

Task	External Milestone	Manual Summary Rollup
Split	Inactive Task	Manual Summary
Milestone	Inactive Milestone	Start-only
Summary	Inactive Summary	Finish-only
Project Summary	Manual Task	Progress
External Tasks	Duration-only	Deadline

Optimum Network (One Wireless Access Point)

Tools	ASSOLO	IGI/PTR	PATHCHRIP
Reading 1	26.6290	4.7320	11.1524
Reading 2	26.6290	2.2820	12.5825
Reading 3	26.6290	3.0910	10.3993
Reading 4	26.6290	7.2190	11.9619
Reading 5	26.6290	2.8450	14.8606
Reading 6	26.6290	4.0710	10.6241
Reading 7	26.6290	3.7200	12.2834
Reading 8	26.6290	3.1420	13.9398
Reading 9	26.6290	4.0070	9.8764
Reading 10	26.8224	4.0070	10.9445
Reading 11	26.6290	5.4270	10.4879
Reading 12	26.6290	4.5950	11.7320
Reading 13	26.6290	2.1610	12.5837
Reading 14	26.6290	5.4320	0.0000
Reading 15	26.6290	4.3560	12.5864
Reading 16	26.6290	3.5390	0.0000
Reading 17	26.6290	5.4450	12.5048
Reading 18	26.6290	4.3400	12.6028
Reading 19	26.6290	7.3500	11.2801
Reading 20	26.6290	5.0090	11.0529
Mean	**26.6387**	**4.3385**	**10.6728**
Consistancy	**0.0432**	**1.3982**	**1.2806**
Accuracy	**100%**	**100%**	**90%**
Failure	**0%**	**0%**	**10%**

Optimum Network (Two Wireless Access Point with Same Bandwidth)

Tools	ASSOLO	IGI/PTR	PATCHIRP
Reading 1	26.6290	1.5610	9.6757
Reading 2	26.6290	2.3500	10.5094
Reading 3	26.6290	0.8920	9.2948
Reading 4	22.8972	1.1990	9.0635
Reading 5	26.6290	0.4560	9.4325
Reading 6	25.2528	0.8860	9.3243
Reading 7	26.6290	0.7910	9.0474
Reading 8	26.6290	1.1790	9.2498
Reading 9	26.6290	1.0320	9.1870
Reading 10	26.6290	1.0590	9.3599
Reading 11	25.4494	0.5320	9.4024
Reading 12	26.6290	0.7570	10.2307
Reading 13	26.6290	0.5140	9.6909
Reading 14	26.6290	0.7910	9.5116
Reading 15	24.6630	1.0450	9.3480
Reading 16	22.8931	1.6220	9.6343
Reading 17	26.0392	0.8820	9.4834
Reading 18	26.6290	1.2920	9.2809
Reading 19	26.6290	0.9060	9.3029
Reading 20	24.8596	0.5680	9.7104
Mean	**25.9116**	**1.0157**	**9.4870**
Consistancy	**1.2187**	**0.4480**	**0.3593**
Accuracy	**100%**	**45%**	**100%**
Failure	**0%**	**0%**	**0%**

Optimum Network (Two Wireless Access Point with Same Bandwidth)

Tools	ASSOLO	IGI/PTR	PATHCHIRP
Reading 1	26.6290	1.8330	9.1725
Reading 2	26.6290	1.7380	9.7824
Reading 3	26.6290	0.8530	9.8208
Reading 4	24.6630	0.4860	9.2731
Reading 5	26.6290	1.0330	9.9523
Reading 6	26.6290	0.5220	9.5138
Reading 7	26.6290	0.6630	8.9735
Reading 8	26.6290	0.5810	10.9210
Reading 9	26.6290	1.4030	9.3311
Reading 10	26.6290	0.7150	9.3946
Reading 11	26.6290	0.5140	9.6764
Reading 12	26.6290	0.4680	9.3391
Reading 13	26.6290	0.3560	9.3755
Reading 14	26.6290	0.8390	9.3665
Reading 15	26.6290	0.8890	8.9996
Reading 16	26.6290	0.7990	9.3420
Reading 17	26.6290	0.6290	8.5959
Reading 18	26.6290	0.8290	9.3153
Reading 19	26.6290	0.8130	9.6714
Reading 20	26.6290	1.0240	9.3415
Mean	**26.5307**	**0.8494**	**9.4579**
Consistancy	**0.4396**	**0.4005**	**0.4656**
Accuracy	**100%**	**25%**	**100%**
Failure	**0%**	**0%**	**0%**

Network with External Traffic (One Wireless Access Point)

Tools	ASSOLO	IGI/PTR	PATHCHIRP
Reading 1	24.6630	0.0000	10.3901
Reading 2	26.6290	0.8930	11.2100
Reading 3	26.6290	1.5060	11.9785
Reading 4	26.6290	0.0000	9.6140
Reading 5	26.6290	1.1560	10.7269
Reading 6	26.6290	1.9280	10.9416
Reading 7	26.6290	0.7390	10.9392
Reading 8	26.6290	0.0000	12.3397
Reading 9	26.6290	2.7430	10.2670
Reading 10	26.6290	2.5650	11.9599
Reading 11	26.6290	1.3840	10.7456
Reading 12	26.6290	0.0000	11.4778
Reading 13	26.6290	0.0000	10.6221
Reading 14	21.6102	0.0000	11.8604
Reading 15	26.6290	0.0000	11.0006
Reading 16	24.8596	2.1620	11.5160
Reading 17	25.4494	1.1940	10.8768
Reading 18	24.8659	2.5330	10.5940
Reading 19	24.6630	1.4550	10.9803
Reading 20	26.6290	0.0000	11.2100
Mean	**25.9459**	**1.0129**	**11.0625**
Consistancy	**1.2818**	**0.6821**	**0.6577**
Accuracy	**100%**	**50%**	**100%**
Failure	**0%**	**40%**	**0%**

Network with External Traffic (Two Wireless Access Point with same Bandwidth)

Tools	ASSOLO	IGI/PTR	PATCHIRP
Reading 1	26.6290	0.0000	10.8718
Reading 2	26.6290	0.8760	9.8687
Reading 3	26.6290	0.8730	10.9372
Reading 4	0.0000	1.4390	10.4654
Reading 5	26.6290	0.0000	10.4210
Reading 6	26.6290	0.8740	11.6975
Reading 7	26.6290	0.0000	9.6913
Reading 8	26.6290	0.0000	9.8659
Reading 9	26.6290	0.5990	9.8659
Reading 10	26.6290	0.0000	10.5792
Reading 11	26.6290	0.8110	9.9634
Reading 12	26.6290	1.1790	9.6524
Reading 13	26.6290	1.7120	9.9634
Reading 14	26.6290	0.0000	9.6524
Reading 15	26.6290	1.2650	10.1807
Reading 16	26.6290	0.0000	9.7254
Reading 17	24.6630	2.2250	10.2090
Reading 18	26.6290	0.0000	8.5357
Reading 19	26.6290	9.7550	9.7709
Reading 20	26.6290	0.8870	9.7709
Mean	**25.1993**	**1.1248**	**10.0844**
Consistancy	**0.4510**	**2.5232**	**0.6448**
Accuracy	**95%**	**30%**	**100%**
Failure	**5%**	**40%**	**0%**

Network with External Traffic (Two Wireless Access Point with Different Bandwidth)

Tools	Assolo	IGI/PTR	Pathchirp
Reading 1	26.6290	0.5940	10.0025
Reading 2	26.6290	1.4620	10.4570
Reading 3	26.6290	0.0000	9.5868
Reading 4	26.4324	0.9210	10.0658
Reading 5	26.6290	0.0000	10.0658
Reading 6	26.6290	1.3130	9.6847
Reading 7	26.6290	0.8650	9.1054
Reading 8	26.6290	0.9770	10.1486
Reading 9	26.6290	1.0570	10.1486
Reading 10	26.6290	1.0420	9.7906
Reading 11	26.3481	1.0460	10.4741
Reading 12	26.6290	2.9240	10.6405
Reading 13	24.8810	0.6390	10.1417
Reading 14	26.6290	0.5730	10.3501
Reading 15	26.6290	1.0300	9.6030
Reading 16	26.6290	0.3850	9.8616
Reading 17	24.6630	0.5440	9.7660
Reading 18	25.6460	1.0390	9.9902
Reading 19	26.6290	1.1150	9.5908
Reading 20	20.2570	1.2490	10.0025
Mean	26.0517	0.9388	9.9738
Consistancy	**1.4857**	**0.5861**	**0.3656**
Accuracy	**100%**	**50%**	**100%**
Failure	**0%**	**10%**	**0%**

Optimum Network

Consistancy	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	0.0432	1.3982	1.2806
Two AP (Same Bandwidth)	1.2187	0.4480	0.3593
Two AP (Different Bandwidth)	0.4396	0.4005	0.4656
Average Consistency	0.5672	0.7489	0.7018
Total Consistensy	0.5980	0.5628	0.5041
Accuracy	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	100%	100%	90%
Two AP (Same Bandwidth)	100%	45%	100%
Two AP (Different Bandwidth)	100%	25%	100%
Average of Accuracy	100%	57%	97%
Consistency of Accucary	0.0000	0.3884	0.0577
Failure	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	0%	0%	10%
Two AP (Same Bandwidth)	0%	0%	0%
Two AP (Different Bandwidth)	0%	0%	0%
Average of Failure	0%	0%	3%
Consistency of Failure	0.0000	0.0000	0.0577

Network with External traffic

Consistancy	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	1.2818	0.6821	0.6577
Two AP (Same Bandwidth)	0.4510	2.5232	0.6448
Two AP (Different Bandwidth)	1.4857	0.5861	0.3656
Average Consistency	1.0728	1.2638	0.5560
Total Consistensy	0.5481	1.0917	0.1651
Accuracy	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	100%	50%	100%
Two AP (Same Bandwidth)	95%	30%	100%
Two AP (Different Bandwidth)	100%	50%	100%
Average of Accuracy	98%	43%	100%
Consistency of Accucary	0.0289	0.1155	0.0000
Failure	ASSOLO	IGI/PTR	PATHCHIRP
One Access Point(AP)	0%	40%	0%
Two AP (Same Bandwidth)	5%	40%	0%
Two AP (Different Bandwidth)	0%	10%	0%
Average of Failure	2%	30%	0%
Consistency of Failure	0.0289	0.1732	0.0000