

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
SCHOOL OF INFORMATION SCIENCE



**DEVELOPING OPTIMIZATION MODEL FOR BANDWIDTH
UTILIZATION BASED ON NETWORK TRAFFIC ANALYSIS
THE CASE OF ADDIS ABABA UNIVERSITY**

KALKIDAN SINSHAW

MARCH, 2016

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**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE
STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE IN INFORMATION SCIENCE**

BY

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NAME AND SIGNATURE OF MEMBERS OF THE EXAMINING BOARD

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DECLARATION

I, THE UNDERSIGNED, DECLARE THAT THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED AS A PARTIAL DEGREE REQUIREMENT FOR A DEGREE IN ANY OTHER UNIVERSITY AND ALL SOURCES OF MATERIALS USED FOR THE THESIS HAVE BEEN DULY ACKNOWLEDGED.

KALKIDAN SINSHAW

MARCH, 2016

THE THESIS HAS BEEN SUBMITTED FOR EXAMINATION WITH MY APPROVAL AS UNIVERSITY ADVISOR.

ERMIAS ABEBE

MARCH, 2016

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Dedication

I would like to dedicate this work to my brother

Mekuria Sinshaw

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First and foremost, I would like to thank Almighty God for making everything possible.

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List of Acronyms

AAU: Addis Ababa University
Bps: Bits per second
DHCP: Dynamic Host Configuration Protocol
DNS: Domain Name System
ETC: Ethiopian Telecommunication Corporation
FTP: File Transfer Protocol
IP: Internet Protocol
IHL: IP Header Language
ICT: Information Communications Technology
ISP: internet service provider
IT: Information Technology
ITU: International Telecommunication Union
LAN: Local Area Network
LUCID: Logical, Useable, Customizable, Interactive, and Drill-down
MRTG: Multi Router Traffic Grapher
MTU: Maximum Transmission Unit
NTA: Network Traffic Analyzer
OPNET: Optimized Network Engineering Tool
SNMP: Simple Network Management Protocol
TCP: Transmission Control Protocol
UNECA: United Nations Economic Commission for Africa
VLAN: Virtual Local Area Network
VPN: Virtual Private Network
VoIP: Voice over IP
WAN: Wide Area Network

ABSTRACT

Organizations make rules for their users in order to optimize network usage and network administrators control the users' network traffic flow over the link. To have full control on activities occurring on network is essential for managing bandwidth utilization to achieve expected service quality. Managing the network is also useful for detecting attacks from malwares, intrusion, or any restricted applications accessing the network. Bandwidth is the most important thing in networking which is the line where traffic data passes through. The larger the bandwidth, the more network traffic flows in it.

This study presents approaches to determine bandwidth utilization by using network traffic analysis. Monitoring traffic data helps to know the bandwidth capacity and to filter applications that make the network crowded with traffic. The ingoing and outgoing traffic is analyzed using solarwinds which is efficient for capturing data from continuous streams of network traffic and convert those raw numbers into easy to interpret charts and tables that quantify exactly how the corporate network is being used, by whom, and for what purpose. Continuously, it records ingoing and outgoing traffic from the router, core switch and firewall devices then logs the data to generate daily, weekly and monthly statistics.

This study shows an effective use of network bandwidth by using network traffic analysis from three campuses of AAU and traffic data recorded from network devices at the university data center which shows the current bandwidth usage of AAU. As the experiment result shows, the bandwidth usage in the university needs to be managed to serve all the university community. Based on network traffic analysis and SARG report, bandwidth optimization model is proposed which considered bandwidth consumption in weekly and monthly within different campuses. Therefore, the ICT office has to take a measure to effectively distribute network bandwidth to campuses.

Key words: *network traffic, bandwidth utilization, bandwidth management*

Introduction

1.1 Background

Nowadays, information technology is part of everyday working environment in any organization. This is because it provides great advantages in reducing cost, saving resources, reducing activities done by human power, increasing productivity and accuracy, creating different alternatives and providing quality services [23].

Network design is one task under information technology which has a great role to in making any institution part of the global, social and technological developments. This will help the organization to perform work activities fast and accurate by introducing latest technologies for the user [1]. When designing a network infrastructure, one of the major considerations is bandwidth usage. Network bandwidth refers to the rate of data which is supported by a network connection or interface and can be measured in terms of bits per second (bps) [2, 3]. Bandwidth represents the capacity of the connection. If capacity is greater, then there will be great network performance.

Network bandwidth management is the process of measuring and controlling the data transmission and other network traffic flow over a network [5]. This helps to reduce unnecessary traffic from passing over the network path in order to avoid crowded network traffic. It is also the role of bandwidth management to share bandwidth for each department in the institution based on its need. Network bandwidth management is useful for controlling unauthorized users from using the network and to differentiate network traffics, giving priority for authorized users [2].

Creating an environment which makes the networking system performance better and considering client's interest in building network infrastructure have great contributions to achieve the desired goal by increasing users' satisfaction. This is because the goal of the service provider is to make users satisfied with the designed service so as come up with a fruitful result. Here the users' interest is to get service that fulfills their need at the right time. Hence, the service provider and user can work together and can come up with the necessary success on

designing network infrastructure as well as the bandwidth utilization and having a great model of applying it.

Managing the bandwidth of a network design is useful for the purpose of improving network performance by controlling unnecessary traffic over the network line. However, some challenges are there when managing bandwidth. It needs the application of tools and techniques. These tools and techniques are expensive and may not be available easily. To go through this obstacle, cost effective solutions should be provided for higher education institutions in order to run the network configuration effectively and efficiently and to manage installed devices [6, 26]. This study is therefore focused on developing optimization model for bandwidth utilization in Addis Ababa University (AAU) network infrastructure. This is done by discovering bandwidth utilization in the university and analyzing the network traffic flow over the link.

1.2 The need of having Bandwidth Management in Universities

The network infrastructure in Universities is meant to support the teaching learning process and research works. This is because Universities need to be connected to a wider academic community in order to operate [17]. It is not possible to access the outside world to undertake and publish research works if there is no internet connection. Even though internet has many benefits, it is also prone to various threats such as viruses, worms, and hackers. Furthermore, people also tend to download and upload bandwidth hungry data like music, movies etc. with a significant effect on the healthy and continuous use of the bandwidth [23]. This usually results in slow response time and poor overall network performance. Researchers, students and the university community at large will not be able to have a working connection to the internet, which in turn results in frequent and numerous support calls. This obviously increases frustration of the support staff. To overcome the above challenges, bandwidth management is very important.

Bandwidth management is the process of measuring communications (network traffic) over the network link in order to avoid filling up the link which results in network congestion and poor performance. By using bandwidth management we can control the performance of the network by removing unwanted network traffic. Bandwidth management demands policies to monitor the whole network. Small number of users may consume large amount of bandwidth. Therefore, Network administrators should investigate which user consumed more bandwidth and for what

purpose. If the user using high bandwidth on unnecessary applications as stated before, they should be restricted for the sake of the majority users who need to use the network for basic purpose [27].

An organization should have a rule or policy which explains about usage of the bandwidth in the organization. If there is a policy in AAU, there will be a method of distributing equal network bandwidth for all university community. Also the ICT office could manage network traffic flows in the university. But AAU has no such bandwidth management because of limited resources including human resource and hardware and software resources.

As there is no bandwidth management as yet in AAU, the researcher tried to develop optimization model for bandwidth utilization. So, the university can implement the model and apply bandwidth allocation system which serves as a mechanism to control the network flow in the campus. There are many tools and techniques which help network administrators to manage bandwidth. The major tools are: Network analyzers to monitor the network traffic, firewalls to block malicious and unwanted traffic, installing anti viruses in order to protect the network from attacking by computer hackers, proxy to effectively use bandwidth and other methods to give priority and control network traffic [17].

Hence, this study discovers network barriers in AAU network infrastructure and tried to bring attention the need for network management and optimization.

1.3 Statement of the Problem

Currently, the interest of doing things in a short time with a minimum resource and increasing satisfaction is the aim of every organization. In this respect, the need for using information technology (IT) in an advanced way is becoming a precondition. To have a great developmental structure, network infrastructure is one of the important factors which facilitate the performance of work. Universities are institutions where big projects and research works are undertaken. In relation to this, IT (especially network connection) has a great role in order to assist these activities effectively and efficiently [6, 7].

AAU has an ICT office which manages the network design and the general ICT infrastructure [4]. It currently has 400Mbps network bandwidth provided by the Ethiopian Telecommunication Corporation (ETC). However, there is no bandwidth management for the network traffic flow as explained above in section 1.2. And the bandwidth allocation system is not based on the requirement of each academic and administrative unit in Addis Ababa University [8]. This is the main challenge which highly affects the network flow in the university.

For instance, researchers may need high bandwidth and strong network performance to download and share online materials as needed; for libraries to make different research outputs, books, and other academic materials digitized and also to serve their users. But some other administrative offices might need less bandwidth usage. Hence, bandwidth management is necessary in order to manage such different bandwidth requirements. In this study, the researcher tested available bandwidth using a traffic data collection tool to know the exact bandwidth offered to the university and analyzed utilization of current bandwidth, see the network performance and proposed a bandwidth optimization model.

Different researches have been done on developing bandwidth model for Universities in Ethiopia. One is by Hailay Weldegebriel (January, 2011) to develop dynamic bandwidth allocation prototype model. However, the scope of his study was Mekelle University. AAU's network design is completely different from Mekelle University. So it needs its own model and quality of design. Another research was conducted by Tsegaye Berhanu (October, 2014) to analyze performance of the AAU wide area network. However, the current research is done to investigate ways of developing optimization model to improve bandwidth usage for AAU network after analyzing bandwidth utilization data.

One of the major reasons that this research is different from Tsegay's work is that he only considered the data collected from one device. i.e. the router at 6kilo campus. But in this study, the researcher went through the data collected from three main devices of the network in the university. The devices that are used for gathering data for this study are: the main router, core switch and firewall. Different data can be gathered from each device. And it is important to see the recorded data on those devices in depth to make a decision to improve the network bandwidth of the university. In addition to this Tsegaye discussed the general idea about network performance, but in this study how to improve bandwidth usage and have a good network flow is described, causes of network problem and solutions are explained clearly.

Therefore, this study tried to propose bandwidth optimization model for bandwidth utilization by addressing the following questions.

- ✓ What is the nature of bandwidth and extent of the bandwidth problem in Addis Ababa University network and what are the causes of this problem?
- ✓ What are the major factors that affect bandwidth utilization in AAU?
- ✓ What are the main challenges that hindered the university from using bandwidth management?

1.4 Scope of the Study

The scope of this research is to develop optimization model for bandwidth utilization to manage the available bandwidth for effective utilization in Addis Ababa university network infrastructure. This is done by collecting network traffic data from network devices including router, core switch and firewall at AAU data center within two months and analyzing the collected data. This study does not include all campus under AAU due to shortage of time and finance. The main campus 6kilo, 5kilo and 4kilo are therefore considered for the study.

1.5 Objectives of the Study

1.5.1 General Objective

The general objective of this research work is to develop optimization model for bandwidth utilization based on network traffic analysis.

1.5.2 Specific Objectives

The specific objectives of this study are:

- To review related works done previously
- To select traffic data collection tool for the purpose of traffic data collection;
- To collect and organize data using the selected tool;
- To conduct network traffic analysis related to bandwidth utilization;

- To identify the network traffic utilization patterns and related problems; and
- To propose optimization model for bandwidth utilization

1.6 Methodology

To fulfill the objective of this research, the researcher used qualitative and quantitative methods of data collection and analysis.

1.6.1 Review of related Literature

Different related literatures have been reviewed in order to have deep understanding of bandwidth optimization model and how it can be implemented in an academic environment. Related literatures have also been reviewed for the purpose of knowing what is done and what should be done to fill the gap.

1.6.2 Data Collection

To analyze the bandwidth utilization of Addis Ababa University, the researcher used documentation from previous works done and evaluates the traffic flow in the university from the main router and core switch to other devices. Interviews have been made with the ICT Experts about the network design, bandwidth allocation and the general network management of the University.

1.6.3 Data Collection Tool

The researcher used SolarWinds toolset to test and evaluate the Network bandwidth of Addis Ababa University. Solar Winds is a powerful and affordable network monitoring software that enables to quickly detect, diagnose and resolve network traffic problems and outages. With deep packet inspection and analysis, the tool provided identification of network traffic and application reliability. Some benefits of solarwinds are: [9]

- speeds troubleshooting,
- monitors & displays response time availability and performance of network devices,

- analyzes user quality of experience using deep packet inspection and analysis,
- improves operational efficiency with out of the box dashboards alerts and reports.

1.6.4 Experimental analysis

Using Solarwinds, the researcher tried to identify the network traffic flow and analyze current bandwidth usage. After analyzing bandwidth utilization from the toolset result, the researcher tried to get the ICT policy of the university and suggest ways of improving network bandwidth usage in AAU.

Finally, the researcher developed bandwidth optimization model for bandwidth utilization in the University. This leads to have full bandwidth management in the AAU network which helps to control the overall traffic flows.

1.7 Significance of the study

The purpose of this study is to provide clear understanding of bandwidth utilization and the network data flow in Addis Ababa University. This study attempted to suggest ways of optimizing network bandwidth through analyzing network traffic flow and finally to design optimization model for bandwidth utilization. The major beneficiary of this study could be AAU, which may use this study to improve quality of service, to evaluate and upgrade network bandwidth, to apply bandwidth management tools and techniques and implementing bandwidth management to control the network traffic flow and create great network infrastructure. Here, if AAU applies this bandwidth optimization model done in this research, there could be an improvement in service provision. Teachers and researchers could therefore benefit from such an improvement in network bandwidth. Students can also benefit with their online study, doing works, creating new ways of gaining knowledge. In general, the University will benefit as it will connect with the world through its network for its academic purpose with better network performance.

In addition to this, any organization can use this research as a base line study to design the performance of its network

Literature review

2.1 Network Traffic

The rapid growth of Internet usage and traffic flow through the network line needs a serious network management. This can include, managing the network traffic by analyzing the data flow, managing bandwidth usage by making policies or applying other control mechanisms.

Network traffic refers to the amount of data moving across a network at a given point of time which flows from a source computer to a destination, which may be another host, a multicast group, or a broadcast domain. Network traffic is the main component for network traffic measurement, network traffic control and simulation and for bandwidth measurement and management [11]. The proper organization of network traffic helps in ensuring the quality of service in a given network. Moreover, various topologies of the network can only be implemented based on the amount of network traffic in the system.

There are different types of network traffic: Busy or heavy traffic in which high bandwidth is consumed, Non-real-time traffic which is the Consumption of bandwidth during working hours, Interactive traffic which is subject to the competition for bandwidth and could result in poor response times if prioritization of applications and traffic is not set, and Latency-sensitive traffic which is a subject to competition for bandwidth and could result in poor response times [11]

2.1.1 Network Traffic Analysis

Network traffic analysis is the process of recording, reviewing and analyzing network traffic for the purpose of performance, security and general network operations and management. It is the process of using manual and automated techniques to review granular-level detail and statistics within network traffic. [2]

Network traffic analysis is primarily done to get in-depth insight into what type of traffic/network packets or data are flowing through a network. Typically, network traffic analysis is done through a network monitoring or network bandwidth monitoring software/application. The traffic statistics from network traffic analysis helps in:

- understanding and evaluating the network utilization,
- download/upload speeds,
- type, size, origin and destination and content/data of packets,

Network security staff uses network traffic analysis to identify any malicious or suspicious packets within the traffic. Similarly, network administrators seek to monitor download/upload speeds, throughput, content, etc. to understand network operations. Network traffic analysis is also used by attackers/intruders to analyze network traffic patterns and identify any vulnerabilities or means to break in or retrieve sensitive data.

Proper analysis of network traffic provides the organization with the following benefits:

- Identifying network bottlenecks - There could be users or applications that consume high amounts of bandwidth, thus constituting a major part of the network traffic. Different solutions can be implemented to tackle these.
- Network security - Unusual amount of traffic in a network is a possible sign of an attack. Network traffic reports provide valuable insights into preventing such attacks.
- Network engineering - Knowing the usage levels of the network allows future requirements to be analyzed.

2.1.2 Network Traffic Monitoring

The ability of a monitoring system to provide accurate information about the nature and type of the network traffic cannot be over emphasized. Information about who is generating the most traffic, what protocols are in use, where is the traffic originating from or where is the destination of the traffic can be very important for solving congestion problems.

Network traffic monitoring is the process of reviewing, analyzing and managing network traffic for any abnormality or process that can affect network performance, availability and security. It is a network management process that uses various tools and techniques to study computer network based communication/data/packet traffic. The key objective behind network traffic monitoring is to ensure availability and smooth operations on a computer network. Network monitoring incorporates network sniffing and packet capturing techniques in monitoring a

network. Network traffic monitoring generally requires reviewing each incoming and outgoing packet [2, 29]

Some of the technologies that incorporate network traffic monitoring include: Firewalls, Intrusion detection and prevention systems, Network monitoring, managing and performance software and Anti-virus/Anti-malware software

2.1.3 TCP/IP Networking Protocols

A protocol is simply a set of rules for communication between computers. The two core protocols are TCP, the Transmission Control Protocol and IP, the Internet Protocol.

1. *Internet Protocol (IP)*

The Internet Protocol (IP) is a network-layer protocol that contains addressing information and some control information that enables packets to be routed. IP is documented in RFC791 and it is the primary network-layer protocol in the Internet protocol suite. Along with the Transmission Control Protocol (TCP), IP represents the heart of the Internet protocols. IP has two primary responsibilities: providing connectionless best-effort delivery of datagrams through an internetwork and providing fragmentation and reassembly of datagrams to support data links with different maximum-transmission unit (MTU) sizes. [12, 25]

IP Packet Format: an IP packet contains several types of information some of them are:

1. Version: indicates the version of IP currently used.
2. IP Header Length (IHL): indicates the datagram header length in 32-bit words.
3. Type-of-Service: Specifies how an upper-layer protocol would like a current datagram to be handled, and assigns datagrams various levels of importance.
4. Identification: Contains an integer that identifies the current datagram. This field is used to help piece together datagram fragments.
5. Protocol - Indicates which upper-layer protocol receives incoming packets after IP processing is complete.

2. Transmission Control Protocol (TCP)

The TCP provides reliable transmission of data in an IP environment and corresponds to the Layer 4 (transport layer) of the OSI reference model. Among the services TCP provides are, stream data transfer, reliability, efficient flow control, full-duplex operation, and multiplexing. With stream data transfer TCP delivers an unstructured stream of bytes identified by sequence numbers. This service benefits applications because they do not have to chop data into blocks before handing it off to TCP. [12]

Instead, TCP groups bytes into segments and passes them to IP for delivery. TCP offers reliability by providing connection-oriented, end-to-end reliable packet delivery through an internetwork. It does this by sequencing bytes with a forwarding acknowledgment number that indicates to the destination the next byte the source expects to receive. Bytes not acknowledged within a specified time period are retransmitted. In this research set of TCP/IP suite of protocols are assessed by showing the percentage of the network protocols. Moreover, the TCP/IP protocols analysis can be used to clearly show the percentage of traffic consumption which can be used as input for bandwidth sharing in intercampus network. The reliability mechanism of TCP allows devices to deal with lost, delayed, duplicate, or misread packets. A time-out mechanism allows devices to detect lost packets and request retransmission.

TCP offers efficient flow control, which means that, when sending acknowledgments back to the Source, the receiving TCP process indicates the highest sequence number it can receive without overflowing its internal buffers. Full-duplex operation means that TCP processes can both send and receive at the same time. Finally, TCP's multiplexing means that numerous simultaneous upper-layer conversations can be multiplexed over a single connection.

To use reliable transport services, TCP hosts must establish a connection-oriented session with one another. Connection establishment is performed by using a "three-way handshake" mechanism. A three-way handshake synchronizes both ends of a connection by allowing both sides to agree upon initial sequence numbers. This mechanism also guarantees that both sides are ready to transmit data and know that the other side is ready to transmit as well. This is necessary

so that packets are not transmitted or retransmitted during session establishment or after session termination.

2.1.4 Packets and TCP/IP

When a file is transferred, it is not sent across the Internet as a continuous block of bits. Rather the file is broken up into pieces called packets, and each packet is sent individually then many different protocols collectively carry out the transfer.

TCP runs on source and destination computers. It breaks up a file to be transferred into packets, sends them out from the source headed for the destination, receives them at the destination, and reassembles them into their proper order.

TCP does the transfer by establishing a connection between the computers. The connection is not a physical path; rather, it is simply TCP software executing on the computers in a coordinated fashion, with each aware that it is working with the other. The connection continues until both sides agree that it is over, or until one side fails to hear from the other for a specified amount of time IP is in charge of routing TCP's packets across the Internet. Each computer has an IP address, a unique 32 bit number. Often, the number is displayed by dividing the sequence of bits into four 8-bit fields, writing each field as a decimal number between 0 and 255, and then displaying the four numbers separated by dots [16].

2.1.5 Network analysis Tools

2.1.5.1 Solarwinds

Solarwinds was founded in 1999 and it delivers powerful and affordable IT management and monitoring software for customers worldwide from Global enterprises to small businesses. SolarWinds is improving the way IT management software is developed, priced, purchased, delivered, and used. The AAU IT monitoring and management software built for System Administrators and network engineers who need powerful, affordable, and easy-to-use solutions that save time and simply get the job done. IT management solutions of AAU can be easier by discovering the bottlenecks of the network using solarwinds.

Solarwinds is selected for this research because it has been used in Addis Ababa university ICT office and was effective. So the researcher believed that using this tool can be effective as the

network of the university was successfully monitored with this tool before. In addition to this, solarwinds is built by network engineers for network professionals, which means it is developed by the professionals themselves. So that it contains the feature that is needed for the job or it is an excellent tool to analyze network traffic monitoring.

SolarWindsNetFlow Traffic Analyzer (NTA) enables us to capture data from continuous streams of network traffic and convert those raw numbers into easy to interpret charts and tables that quantify exactly how the corporate network is being used, by whom, and for what purpose. [9].

Some features of solarwinds are:

Automated Network Device Discovery: Schedule network scans from an easy to use, Web-based discovery wizard; identifying new network devices and ensuring us are monitoring all of our critical equipment.

Multi-Vendor Device Support: Gain out of the box, multi-vendor device support for today's complex network environments. SolarWinds monitors availability and performance statistics for any router, switch, firewall, VPN concentrator, wireless access point, and other devices that support standard protocols.

Hardware Health Monitoring: Get at a glance insight into the health of the network hardware by monitoring, alerting, and reporting on the state of key device sensors including temperature, fan speed, and power supply.

Intelligent Network Alerting: Quickly configure alerts for correlated events, sustained conditions, and complex combinations of device states. Topology and dependency-based alert suppression enables us to intelligently escalate alerts for issues that are truly critical.

Drag-and-Discover Performance Charts: Accelerate and simplify network troubleshooting with real time, interactive charts and graphs of key device performance statistics.

Network Availability and Performance Monitoring: Deploy an array of network discovery tools including Port Scanner, Switch Port Mapper, and Advanced Subnet Calculator.

Network Monitoring: Monitor network device and interface availability and performance indicators, such as bandwidth utilization, packet loss, latency, errors, discards, CPU, and memory for SNMP(Simple Network management Protocol)and WMI (Windows Management Instrumentation)enabled devices.

Do it ourself-Deployment: Download, install, and deploy Network Performance Monitor in less than an hour, using three simple steps.

Connect NowNetwork Mapping: Drag and drop network devices to custom network maps and automatically view connections between devices and their real-time status.

Intuitive LUCID Interface: Simplify network troubleshooting with a Web interface that is Logical, Useable, Customizable, Interactive, and Drill-down (LUCID).

Centralized Message Center: Get a central view for all of the notification messages about our network's performance so we can streamline troubleshooting with alerts, data, events, traps, and other messages in a single interface.

Dynamic Service Groups: Group network devices by virtually any category and roll up network performance and service level status by location, business center, or any other grouping.

Customizable Performance and Availability Reports: Generate network performance reports using out of the box templates that can be customized with a few mouse clicks; automating report creation and distribution.

Integrated Wireless Polling: Manage wireless thin and autonomous access points and their associated clients. Now SolarWinds can monitor our wireless devices alongside our wired devices and provide you with alerts, reports.[9]

2.1.5.2 Multi Router Traffic Grapher (MRTG)

MRTG is a tool that was originally developed by Tobias Oetiker. The main purpose of this tool was to provide a convenient method to gather statistics from routers via SNMP and present them in an easy to understand graphical format through a web server. However, the tool quickly expanded to be a general purpose tool by which any information that can be represented in a machine readable numerical format can be captured and displayed. This works through traditional SNMP data gathering techniques, but also through custom scripts that can be created to present the information to MRTG in a manner it can understand, record and display.

After some time, MRTG began to demonstrate some operational issues with respect to inefficient methods of creating the graphs and having no theoretical cap on the size of the log fill. MRTG requires limited storage, but it rapidly loses resolution, useless for capacity planning and graph can't be directly compared on MRTG [13].

2.1.5.3 *Optimized Network Engineering Tool (OPNET)*

OPNET is one of the Network analysis tools which Provides a comprehensive development environment for the specification, simulation and performance analysis of communication networks. A large range of communication systems from a single LAN to global satellite networks can be supported. Discrete event simulations are used as the means of analyzing system performance and their behavior. OPNET is not effective because of some limitation like, the result may not accurate as it depends on the sampling resolution and simulation is inefficient if nothing happens for long periods [14].

2.2 **Bandwidth**

Bandwidth represents the capacity of the communication media to transfer data from source to destination and also responsible for data transfer speed and commonly used in Internet connections. Bandwidth is both absolutely and relatively much more expensive for any institution. Many academic institutions are finding that they still do not have reliable, usable internet access for their students and staff [17].

In other ways, bandwidth in developing countries is very expensive, because of which most higher education institution cannot offer much bandwidth. According to [17] the following are the main reason for the expensive cost of bandwidth in developing countries

- In many cases, Internet access to the country is available only via satellite connections, which are much more expensive than cable
- Where marine fiber cables do exist, they may not carry enough traffic to achieve the economies of scale that make transatlantic bandwidth to Europe, for example, so affordable. In some of the countries that are connected via a marine fiber cable, the telecommunications infrastructure for connecting it to most of the country does not exist.
- The wired telecommunications networks in many developing countries reach only a small part of the population, and many areas (even parts of cities) are not covered at all. The development of wired networks cannot follow the same course as it did in industrialized countries owing to small populations or low population densities in some areas, poverty, the rise of mobile and satellite communications.

- Bandwidth is also expensive due to the comparative weakness of the currencies of developing countries that have to pay in US dollars or Euros or other major currencies for most or all of their upstream international bandwidth
- While the cost of the telecommunications link between two countries is generally shared, in the case of African countries (and possibly of many other developing countries) the cost of the international link is paid for entirely by the African country. This amounts to reverse subsidization of developed countries. Considerable congestion exists at ISPs where many users share a small amount of bandwidth; ISPs simply have too many customers for their capacity
- Inter-country links do not exist between most developing countries. For example, most communications between African countries must be routed at great expense through Europe or the USA.
- Communications and computing equipment is expensive for African organizations as a result of weak currencies, high transport costs, small budgets and high tariffs. In many African countries computer equipment is classified as a luxury item and taxed accordingly, though this counterproductive policy is likely to change in the medium term.
- Some telephone companies that have telephone lines lack the capacity (owing to low demand) to create leased-line connections. Low demand exists mainly because many companies and institutions bypass the national telecommunications grid by using VSAT.
- Leased lines are sometimes analogue instead of digital. On an analogue line, a modem is used for digital transition (such as connection to the Internet), resulting in a maximum speed of 56 Kbps. Digital lines are capable of much higher speeds

As bandwidth is an expensive resource, organizations should ensure that they are purchasing the right amount of bandwidth, and test whether they are getting what they pay for. A university should also aim to use the available bandwidth as best it can, not only by limiting abuse but also by providing access to as many people as possible in order to maximize the use of the resource. AAU should have to increase its bandwidth even though it is expensive resource. Typical reasons include:

- The university service is becoming provided in digital format over the internet and communications are through email.

- Number of Students and staff members increase from time to time, this tends to get crowded network. For example, the number of students who entered AAU in 2000E.C was 14311, in 2004E.C increased to 14864, in 2007 & 2008 E.C increased to 16214 and 17517 respectively according to date obtained from registrar.
- The volume of resources on the Internet keeps growing, and tends to become ever more bandwidth hungry.
- New services on the Internet, such as streaming media, may present new opportunities for education, though it is also possible that streaming media will prove to be useful for entertainment.

2.2.1 Bandwidth Management

Bandwidth management is a generic term that describes the various techniques, technologies, tools and policies employed by an organization to enable the most efficient use of its bandwidth resources. Bandwidth management is a process of allocating bandwidth resources to critical applications on a network. The aim of bandwidth management can be achieved by removing unnecessary traffic and improving the performance of an Internet connection. The goal of managing network capacity is to have the right amount of bandwidth in the right place at the right time for the right set of users and applications. There should be always efficient use of bandwidth. i.e. the minimization of unnecessary bandwidth consumption and the delivery of the best possible levels of service for users [15].

In Bandwidth management, we manage the data flow restricting unauthorized traffic and making reserves for the authenticated one. The performance of the existing Internet Connection can be enhanced by monitoring and controlling mechanism and this is known as bandwidth management [30]

AAU network bandwidth size cannot meet the ever increasing user demands if there no effective bandwidth management strategy. It is necessary for any network design to have simultaneously good content in appropriate formats, good local network management and design, good bandwidth management policy, and user education to understand their responsibilities to use the

scarce and expensive resource effectively. Bandwidth management involves the creation and enforcement of network policies to ensure fair and satisfactory network performance. It becomes the tool used to ensure enough bandwidth is available to meet the traffic needs of those mission-critical and time-sensitive applications and prevents competition between these applications and lower priority traffic for the limited network resources. Bandwidth management has the goal to ensure the availability of Internet bandwidth to everyone [15].

Bandwidth management requires three activities: (i) Policy, (ii) Monitoring, and (iii) Implementation. If any one of these activities is missing then the management of bandwidth is significantly compromised.

Monitoring is important for defining and enforcing policy. Network monitoring informs the process of creating an enforceable policy that reflects the actual needs of the user group. It is also the necessary part of enforcing policy. Furthermore, monitoring is also required to diagnose faults and troubleshooting of the network. Without an Acceptable Internet Usage Policy no amount of bandwidth is enough to satisfy the demands of an unrestricted user community. Individuals downloading music and other files for their personal use can absorb an institution's bandwidth. Frequently it is the minority that consumes the majority bandwidth. In this situation, user education is far more productive than technical solutions. The institution's policy needs to be understood and enforced. It becomes the responsibility of the network administrators to find out which users are not adhering to the policy and to interact with them on a face to face level [31, 32]

2.2.2 Issues to be addressed in Bandwidth Management

The day to day growth of internet usage makes the network management a challenging task. Managing the network flow, discover who is generating high traffic and from where this traffic is originating is important to solve network problem. Here, there will be fair distribution of network bandwidth for the purpose of achieving the mission of the university.

In AAU network, if more money is invested on bandwidth to support unlimited recreational applications, the cost will drive up without addressing educational purpose. If unlimited bandwidth access is allowed to recreational applications on limited bandwidth, students will not

be able to reach the legitimate educational resource materials. From the analysis it is found that there are a number of applications which consumes the campus bandwidth inappropriately. Hence, such applications should be identified based on the time intervals and make dynamic bandwidth allocation to have fair bandwidth distribution amongst the users in a specific geography.

2.2.3 Bandwidth Utilization and Management Challenges

Nowadays many organizations are dealing with a high speed internet service in order to speed up their business. However, high cost of bandwidth makes difficult for universities to significantly expand their Internet bandwidth [15]. Some of the challenges in utilization of the bandwidth of AAU are:

- In Addis Ababa university internet users are increasing from time to time which makes the network traffic crowded
- There are viruses that are coming from the internet like spy ware and adware advertising which releases unwanted data and broad cast loop file to the network
- Internet service provider which are not able to provide accurate service affects utilization of bandwidth
- Limited bandwidth which is not balanced with the demand
- Network bandwidth breaks because of need of upgrading device

In general the following are main challenges relating to bandwidth management according to [6]:

Increasing Awareness: Although there are technical issues relating to bandwidth management, the biggest challenge is to raise awareness of the importance of managing bandwidth. Bandwidth is a limited resource that needs to be shared. Bandwidth has a cost and policy should govern its use. Just as with a phone line, use of bandwidth should be monitored and managed.

Improving Skills: Capacity building and skills development are fundamental to improving bandwidth management Practice within developing world institutions. Institutions have put forward a strong demand for bandwidth management training, even amongst those institutions that have organized some form of training in the past. The challenge is to provide comprehensive

training on policy and the purpose of bandwidth management for managers, integrated with hands-on technical training for network administrators.

Providing Appropriate Tools: in many institutions the necessary tools for bandwidth management are not yet present and if they are present they may not be used to their full extent. Higher education institutions are expected to deal on bandwidth management, discovering tools and would answer the following questions [6]:

- Are the tools appropriate for this audience?
- Are there significant gaps in the functionality of existing tools?
- How can the most appropriate tools be integrated into a wider program of bandwidth management and training?
- Can any existing tools be leveraged for use by small or overstretched IT teams?

2.3 Related Works

Different researches have been done on network bandwidth management locally and internationally. From among these 3 local researches and 3 global researches are reviewed which are considered highly relevant for this work.

2.3.1 Local Researches

Hailay[2] attempted to develop a dynamic bandwidth allocation prototype model for campus network based on network traffic analysis and propose algorithms for different dynamic bandwidth allocator components. In his work, the researcher used ntop and MRTG for online traffic analysis as they are used for analyzing protocol distribution and Network traffic analysis at different links. The offline network traffic analysis is based on the server log file which is taken from Mekele University web server.

Haily analyzed the ingoing and outgoing traffic load using Multi Router Traffic Grapher (MRTG) which is a versatile tool for graphing network data. As discussed in his research, the MRTG reads the inbound and outbound octet counter of the gateway router every five minutes, and then logs the data to generate daily, weekly, monthly and yearly graphs for web pages. And

weblog analysis consists in measuring the usage of relevant traffic activities. Based on the traffic analysis, he proposed a dynamic bandwidth allocator algorithm which consists of modules such as administration tool, which provides a graphical interface for configuring bandwidth allocation based on the different bandwidth demand in the intercampus network; policy agent, packet selector, bandwidth estimator and the like.

The strength of Hailay's work is; it focused both on real time and off line network traffic which is good for making decision and he analyzed network traffic and proposed ways to detect intrusion and malicious attack. The network analysis could also help in allocating available bandwidth at the end users. The weakness of his work was that he does not properly explain the reason why he used the methodology; he used network traffic analysis tools but didn't describe why he selected those tools for his work.

Another local research on network performance analysis was done by TsegayeBerhanu[4]. His study aimed at investigating the effects of different WAN factors using performance analysis tool, with the view to develop a WAN optimization framework that can improve the performance of the AAU network traffic flows over the WAN link. Tsegaye tried to conduct experiments using real-time cases which are taken from the AAU WAN environment. The experimentation was conducted through three phases.

1. network traffic data is collected using Network Performance Monitor (NPM) tool from the AAU WAN environment,
2. then analyzed the collected data and evaluated to investigate the network performance using metrics such as network availability, response time, packet loss
3. Finally based on the analysis result a WAN optimization framework developed. To develop the WAN optimization framework the researcher followed some steps such as Network Condition Recognizer, WAN Bottleneck Determiner, Optimization Solutions Provider and Event Reporter.

From the conducted experiment he got a result that high response time rate, high packet loss rate, and fluctuating network availability is exhibited in the AAU WAN environment. Tsegaye designed a frame work which to upgrade AAU WAN architecture for improving Network performance. He also identified the bottleneck that affects the network traffic to discover high

traffic nodes. As a drawback of Tsegaye's work, the data was collected during the semester break which is the time when the number of students and teachers in the campus is less. Also there is area limitation because he covered only network traffic analysis at a single Node from 6kilo data center.

Another study was done by Yacob Gobena[18]. He discussed about the performance impact with various network factors in UNECA. Yacob developed WAN optimization model in order to improve the performance of business critical applications in the organization which are deployed over WAN. To conduct his study, Yacob captured traffic statistics data using Net Flow analyzer from the organization where the research was undertaken. Then he imported the traffic statistics data to OPNET Modeler tool and analyzed the application performance. After analyzing the performance, Yacob benchmarked the performance of critical applications. And then he developed WAN optimization algorithm based on the benchmarking result. Finally, he evaluated the developed algorithm for its effectiveness on improving the performance of critical applications that are deployed in WAN environment. From his result, Yacob identified problems related to WAN performance like Email segment delay, end to end delay, HTTP protocol chattiness etc. He also evaluated different optimization techniques and got good performance result. The strength of Yacob's research is that, it provided findings by identifying the application optimized condition when deployed over WAN. His designed framework can be transformed into commercial application and enterprises with low network resource can benefit as the optimization solution addresses common performance issue of such WAN environment.

Further, the research done by Yacob provided clear and justified methodological approach to study performance problem of WAN in any organization. Even though Yacob's research has great benefits, it has a limitation. The model validation was done on simulated environment rather than actual environment. He did not clearly state whether he considered real time network flow.

2.3.2 Global Researches

[15] Presents a research undertaken to investigate the issue of how to maximize or make efficient use of bandwidth. In particular, the research sought to find out about what universities in

Zimbabwe are doing to manage their bandwidth. In order to meet the study's objectives, a mixed methods approach was used to gather relevant data. The research considers the bandwidth management techniques in five universities of Zimbabwe [15].

The result of the study done on Zimbabwe universities showed that the status of internet access in those universities is different in levels of computer access among the institutions.

Their study indicated that, increasing the size of bandwidth and the provision of technical tools alone is not sufficient for effective bandwidth management. Instead there is a need for IT directors and university administrators to balance increased bandwidth access demands with investment in bandwidth management strategies.

A two-pronged approach of self-administration of emailed questionnaire and phone interviews were used to gather the relevant data.

1. The status of Internet access in Universities in Zimbabwe

As the researchers discussed in their work, there were large differences in levels of computer access among the institutions. The average across the sample was 6.8 users per computer, with 3.5 users per networked computer as the university had the best ICT resources. However, it was a high ratio compared to the average students per networked computer ratio of USA institutions, which is thought to be about 3 per computer.

2. Bandwidth Utilization Pattern

Researchers showed that bandwidth utilization pattern for one of the universities indicated the university working hours start from 8:00 am to 10:00pm and bandwidth availability was fairly good at all the universities

3. Bandwidth Management Strategies Employed

From the data collected they (the researchers) concluded that universities were not taking bandwidth management seriously which was evidenced by the lack of a bandwidth management policy at all the universities. In general it was investigated that only some IT directors are trying to create effective bandwidth management in universities where the research was conducted.

[19] Discussed to design and analyze policy framework for optimal utilization of internet bandwidth by considering Himachal Pradesh University. The article [19] tried to identify

unproductive web application that is responsible for eating valuable bandwidth of the university. Monitoring the network traffic was conducted by configuring Cyberoam as a gateway between the university network and out world environment. As a general work, Cyberoam and ERNET tools were used for network traffic report and bandwidth usage graph respectively.

Cyberoam deliver complete range of security features including Virtual private network, secure socket layer and gateway anti-spam. Then completed detail analysis of report by categorizing applications as a productive (academic and research) and unproductive (personal and nonacademic). After identifying and categorization of applications bandwidth utilization was designed for the university.

The major finding of the study done in Himachal Pradash University indicates that: - there is a need to block some web application like social network, audio and video download. And network traffic related to update any application was blocked in working hour. The protocol application category blocked. Then some servers like mail server, web cache server, window update server were installed to minimize traffic on network by resolving user request locally.

The main advantage of the policy recommended was that university can be successful to reduce the bandwidth load significantly and a policy can be designed for their network bandwidth utilization. And enhancement of response time should be considered.

However, there were drawbacks observed on the implemented policy suggested the study done in Himachal Pradash University. Because the policy was not implemented from appropriate level of authority and no agreement was signed between the users and the university. Additionally, the design and implementation of the internetwork access can't be fully the responsibility of the network administrator or other technical persons only. There should be supportive attitude of the University administrative and management people.

Henrik Abrahamsson[37] presents a model of web client traffic. He derived empirical probability distributions describing session lengths, time between user requests for web pages, and the amount of data transferred due to a single user request

METHODOLOGY

3.1 Introduction

Nowadays, the need for network bandwidth requirement is increasing due to the increase in popularity of entertainment media like YouTube, social media and in general the increase in users and usage from time to time. Same scenario is true for AAU. Because of this, there is no doubt that there must be a need to have limit placed on bandwidth that is used for this media in the University. It can be useful to utilize the limited bandwidth provided for the university. This must be done without affecting the critical functions of the university. It has to be done to effectively utilize the available internet resource for the benefit of all the university community [2].

Bandwidth management is a task of controlling the amount of links which result in poor performance by measuring and controlling the traffic packet in the link [17]. A bandwidth management tool provides management for sharing available bandwidth.

By having the network traffic analysis it is possible to set bandwidth management which may help Addis Ababa University to have a good network flow by blocking different applications that consume high rate of bandwidth but are less important. Additionally, network bandwidth can be managed by establishing priority based on user web category group and applications with precise bandwidth usage of a day.

3.2 Network Infrastructure of AAU

Until now all of the branch campuses of AAU except 5kilo, 4kilo, black line and College of Business and Economics campuses are connected with VPN which is provided by ETC. The 5kilo, 4kilo, Black Lion and college of business and economics campuses are connected with fiber cables directly to 6kilo campus network. However, there is a network connection problem and the University needs to have a solution to provide good network usage for its community. In general the network infrastructure of Addis Ababa University is now designed using Virtual

Local Area Network (VLAN). The network design is using VLAN because most of the buildings in AAU are large and host different departments.

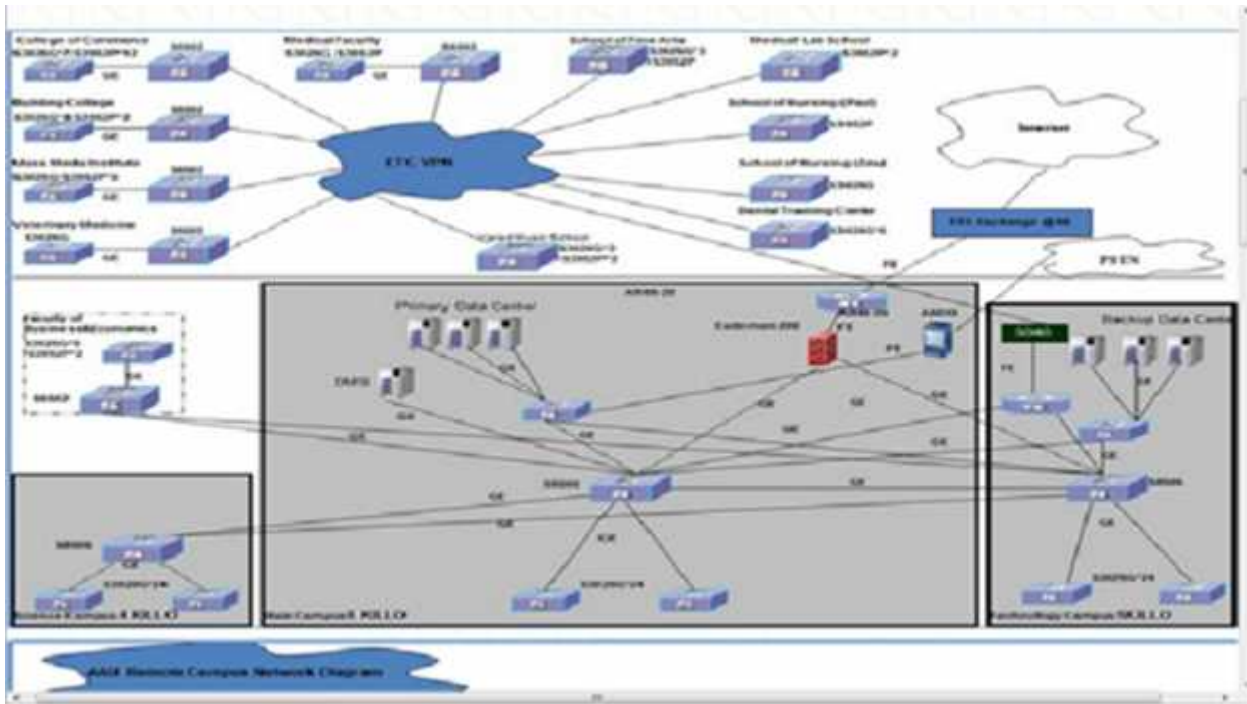


Figure 3.1 AAU network design.

VPN (virtual private network) is a kind of technology which can be used to access private network from remote host which are not physically connected to the private network [20]. Because it is cheaper than leased line, it is commonly used to connect offices. AAU campuses other than the major campuses are connected with this technology.

VPN constructed within public network infrastructure such as global internet which help if customer wants to share their own private network. And it is needed when an organization has many locations with longer distance and there is less bandwidth. It helps to connect different branch campuses.

Using dedicated leased circuit AAU network established fixed resource level available to it. It is possible for Addis Ababa University to receive VPN internet service from ETC which is the comparable service level that attempt to guarantee the level of the University resource which the VPN can be drawn from underlying host.

When we design a VPN there are issues which need to be considered. We have to consider security in order to protect the file sharing so that data transfer process will not be accessible to the outside world and we have to consider the number of location and number of users. In using

VPN, legal users should be able to use ping continuously and should have good performance all the time and only authorized people should get the data Confidentiality and privacy so that there will not be snooping and wiretapping [21].

AAU takes advantage of the virtual private network technology that reduces bandwidth requirement and supports windows and UNIX operating system. Even though VPN reduces bandwidth consumption, bandwidth management is a big problem in AAU as explained by the ICT expert consulted.

VPN has its own draw backs that it doesn't offer security which makes the connection easily attacked by different malicious programs like spyware. In order to fill the gap in security problem, various techniques are being used in AAU. AAU has adapted ICT technology as a strategic tool to achieve its mission and vision. Proper integration and managing ICT resources is the major issue in the University [20].

3.2.1 AAU Data Center

Data center is a center where a collection of server machines within racks and equipment to design a cabling and switching architecture that supports rapid change and mobility and accommodate transitions [33]. Data centers in large university and private enterprises are helpful to consolidate their IT service and also to run large scale data intensive task.

In AAU data center there are more than 25server computers that are operated by the ICT office including servers. Additionally, other server machines are configured in branch campuses. The main data center is at 6kilo in which the Proxy server, DNS and DHCP are run from [8].

3.2.2 Application and Services of AAU Network

Services provided by AAU Network can be grouped in to two. The first one is technical support services that are technical in nature and done to maintain equipment and service level in house. Some of the services are DNS, Proxy server, fire wall. The second types are those services provided directly to users like email, internet, elearning.

The AAU network is used for different services and applications like web service (using word press), email service (using Google), elearning(using moodle), FTP service, DHCP service, etc.

Identifying factors for bandwidth utilization problem in AAU is the main part before examining how to improve the bandwidth usage [8]. Based on the interview conducted with domain expert of ICT office, the following service problems were identified: fluctuation of network availability, unable to transfer file using FTP, crowded bandwidth. The expert discussed reasons for AAU network degradation: lack of bandwidth management and old devices used in the university. Knowing current network utilization will be the first issue to be done by network administrators to know the problem and take measures to improve the network performance.

3.3 Selection of Performance Metrics

After identifying the network traffic problem, this study used bandwidth utilization as a performance metric to complement the previous researchers which used other performance metrics like response time, packet loss and network availability.

3.4 Selection of Network Traffic Analysis Tool

Controlling network traffic is becoming complex through time because of different network media in organizations. When networks become vast and various, managing the network will be expensive. For this reason, there is a need of using automated tools and techniques in order to support human endeavor, to collect information about the usage of the network.

In this study network traffic monitoring tool is used for data collection and analysis Solarwinds testing toolset that is helpful for today's network management and consulting professionals is used.

For the experimentation of analyzing the network traffic flow from the main router, core switch and firewall, tools and Performance metric that are described in the methodology section chapter one are used. The data is collected and analyzed by the Network traffic Monitor. It is a real time network monitor able to track network latency at the node level and defined in terms of network availability and bandwidth utilization. The Network traffic Monitor provides two different levels of monitoring. Devices that support SNMP can be monitored for network latency that provides traffic statistics, and supply detailed management information. Devices that do not support SNMP can provide network latency information. The experiment in this study used a Network traffic monitor toolset (Solarwinds) version9. The toolset is a collection of network management,

monitoring, and discovery tools to achieve the desired goal on measuring network bandwidth utilization and to manage the traffic flow, status of the network.

The Solarwinds toolset provides tools needed by the network professionals to go on the work. SolarWinds is developed by network engineers and provides tools for the network professionals. Discovering and knowing the network traffic data helps to get the barriers of the traffic that affect the AAU Network bandwidth utilization. And the effect of this bandwidth usage influence experimented in the analysis phase to fulfill the objective of the study. The selected monitoring tool has been configured to record network traffic data from the selected server machines (i.e. the main router, fire wall and core switch) of the University. The network traffic data is gathered by concerning different features of the AAU network environment, which includes network availability and bandwidth utilization. The main bottlenecks that have an effect on network bandwidth can be determined from the collected traffic data. The following chart from figure 3.2 displays how the network traffic monitoring tool collects and analyzes network traffic data.

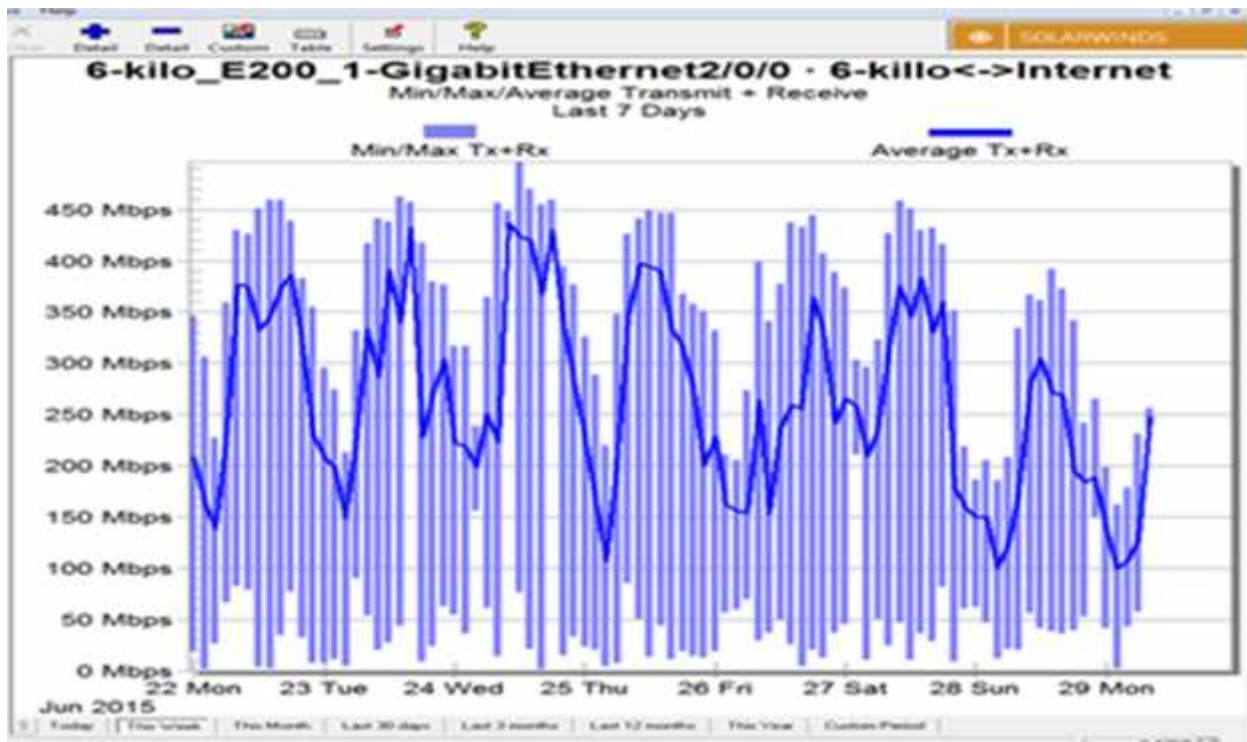


Figure 3.2 Overview of Network traffic data monitoring tool

3.5 Bandwidth Utilization

Due to the explosive growth of internet and internet deployment for constantly growing variety of applications, need for bandwidth has emerged with issues like performance, predictable quality of service and different network service. Need for measurement technology, monitoring network utilization and performance also emerged as serious issues. Bandwidth (rate of data which is supported by a network connection) and latency (the time taken for sending packets) are the two key performance parameters and utilization indicators, helpful for network management task that includes application and user profiling, proactive and reactive resource management and traffic engineering [22]. The following are factors to consider when monitoring bandwidth usage:

- The first factor considers bandwidth utilization.
- Another factor to take into consideration when monitoring bandwidth utilization is the source of bandwidth consumption. Sometimes, when considering deployment an administrator feels obligated to increase available bandwidth so that the application will not experience issues. However, the budget in the organization may not be enough and purchasing additional bandwidth requires additional cost and a clear justification about the need of increasing.

The first step to justify bandwidth management for AAU network infrastructure is to determine what the current utilization level is on a network link, and second is to trend the actual requirements of the application then propose optimization model for bandwidth utilization and investigate the difference.

3.5.1 Bandwidth Management Based on Network Traffic Analysis

Network traffic analysis based bandwidth management helps enterprises to establish priorities based on users, web category, groups and applications with precise bandwidth allocation based on usage and time of the day [34]. Network traffic analysis based bandwidth management is useful to discover high bandwidth consuming applications and then to block access to audio and video downloads, gaming, tickers, ads, etc which consume high bandwidth. Therefore, high bandwidth requiring applications like VoIP will be given adequate bandwidth. This way, enterprises can adjust their bandwidth policies and usage trends based on user requirement in

order to improve the network traffic flow. Bandwidth management is the process of measuring and controlling the communications (traffic, packets) on a network link, to avoid filling the link to capacity or overfilling the link, which would result in network congestion and poor performance [2]. Network monitoring is the ongoing process of collecting information about various aspects of network operations. Hence, examining the above bandwidth consumption trends can help identify unauthorized network access, network errors, and recognize activities that may cause potential problems.

3.6 Methods of data collection

The researcher selected a network traffic data collector called solarwinds and installed the toolset in order to collect network traffic data from AAU network devices and analyzed the collected data of network bandwidth utilization in the university. The ICT expert in the University was interviewed for this study. The interview has been used for this study to get full information about the network infrastructure and configuration of AAU. Different literatures have been reviewed to understand the works done before and to know the gap.

Finally, the researcher proposed bandwidth optimization model for AAU network bandwidth utilization based on the network traffic data collection and analyzing result.

3.6.1 Managing Network Capacity

Most of the network links are shared between multiple users or applications. Hence, network bandwidth management tools provide the control mechanism for this. Bandwidth management can be done by upgrading the capacity of the link when it is congested. For example, it is possible to predict temporary link congestion at some time during the day. However, it may not be possible to predict when large files are being transferred or a certain website is taking up a whole lot of network traffic [2]. If network usage is average within the available capacity, the performance of the network can be improved by allocating bandwidth to a particular type of traffic.

3.6.2 Network Traffic Analysis of Addis Ababa University

In this research, the researcher concentrated on network technologies that are common in both industry and academic environments. So here, the researcher assumed such network technologies

to consist of Ethernet links (normal, Fast and Gigabit) which are connected by hubs, switches and routers. In general it is important that normal network operation should not be disturbed by the measurements. For example, it may not be acceptable to interrupt network operation to install optical splitters that copy all network traffic to a measuring device.

Network traffic data is collected and analyzed by considering various features of AAU network environment which include network availability and bandwidth utilization among each VLAN. Here, the collected data help to determine the major factors that affect bandwidth utilization of the AAU network.

To measure the performance of the network bandwidth utilization, the following steps are applied.

1. The initial step is installing and configuring a network performance testing tool, (Solarwinds toolset) in order to measure and monitor network traffic of Addis Ababa University.
2. After installing the testing tool, the tool started to capture network traffic data statistics from AAU network link and then it analyzes the data.
3. Finally, the evaluation of AAU network bandwidth utilization taken place and bandwidth optimization model has been developed.

3.6.3 AAU Network Node

A Node is any network managed device which helps to capture network traffic data. This study is conducted on real time environment and squid data (online accessed data by the AAU network user) that captured from the AAU server which represents the University network scenario.

To do the experiment managed devices (router, core switch and firewall) which have unique IP address have been added to capture the network traffic statistics data. Then simple network management protocol was enabled on the router, core switch and firewall.

After the network traffic monitor toolset installed on the computer, an IP address and community string was added to access the remote devices. Real time traffic flow is collected and analyzed in terms of bandwidth utilization.

The analysis is done using network traffic monitoring tool which captured the data from router, switch, and firewall. Node must not be on same network rather it must be reachable from computer on which network traffic monitor installed.

Experimental analysis and model development

The Network traffic data is collected from the main router in Addis Ababa University (6kilo AR46GW), the Fire wall (6kilo_ E200_1) and the core switch of the university (6kilo_s8505_1). This study focused on developing bandwidth optimization model based on the two months report of June and July.

4.1 Data Collected from the Main Router

A router's functions are: to read the destination address, to consult its internal information to identify an outgoing link, to forward the packet by examine a packets destination address and determine the best path by using a routing table. A network link that connects two routers is limited by how much data it can transfer per unit of time, commonly referred to as the bandwidth or capacity of a link. The data is collected from main router in AAU 6kilo campus during June and July.

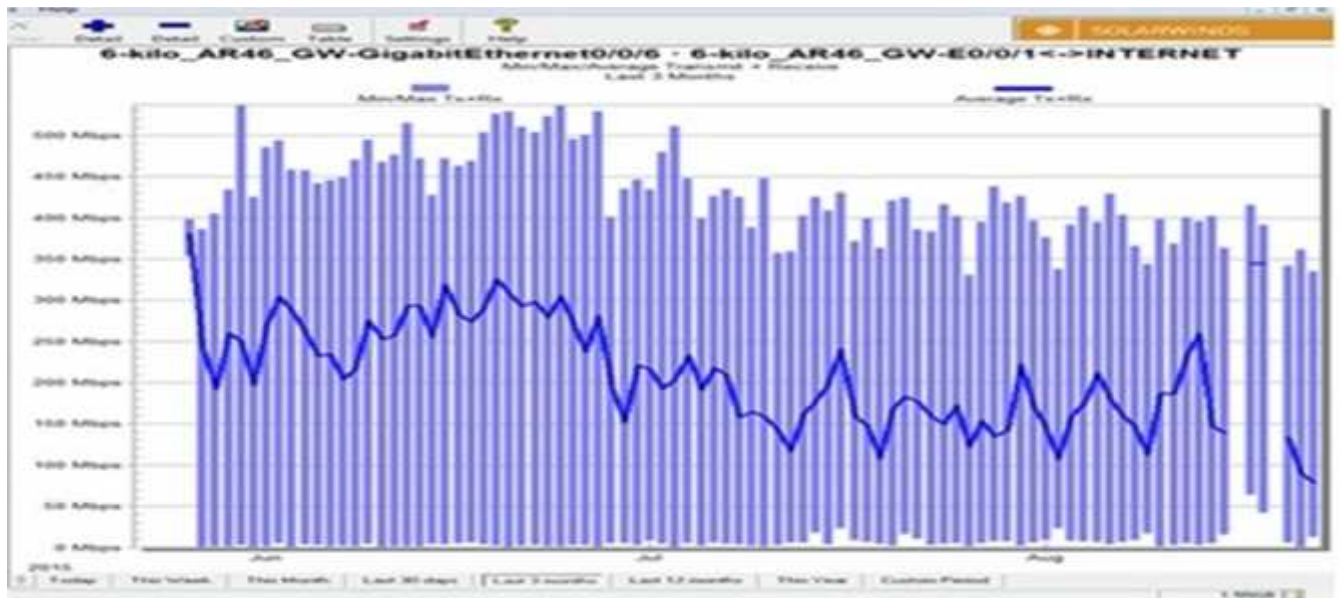


Figure 4.1 Minimum, maximum and Average data transmitted and received from 6kilo main router within two months

Months data recorded	Maximum	Minimum	Percent utilization	
			Max	Min
June	June 24	June 28	137.5%	100%
	550mbps	400mbps		
July	July 3	July 26	127.5%	83.3%
	510mbps	333mbps		

Table 4.1 Minimum, maximum and average data transmitted and received from 6kilo main router

The above figure and table shows the data collected from 6kilo main router and the minimum, maximum and average data transmitted and received. As shown from the figure, the highest bandwidth usage rate in June was recorded on June24 that is around 550mbps with 137.5% percent utilization. The minimum rate during this month was on June 28 that is around 400mbs, with 100% percent utilization. Starting from July the highest rate was recorded on July3 around 510mbs with percent utilization of 127.5%. The minimum data recorded during this month was on July26, 333mbs with percent utilization of 83.3%. From the above data it is concluded that the bandwidth utilization was very high on June as the number of internet users was high. This is because the regular students were there in the university. Here the minimum bandwidth utilization was recorded on July. As the researcher interviewed from the ICT expert and as the data shows that, the bandwidth usage was less during July because regular students need high bandwidth than summer students. The number of students and staffs is high during regular classes. Most of the lecturers on summer time have their break which makes the bandwidth free. The toolset also displayed the data in weeks as shown in figure 4.2 and 4.3

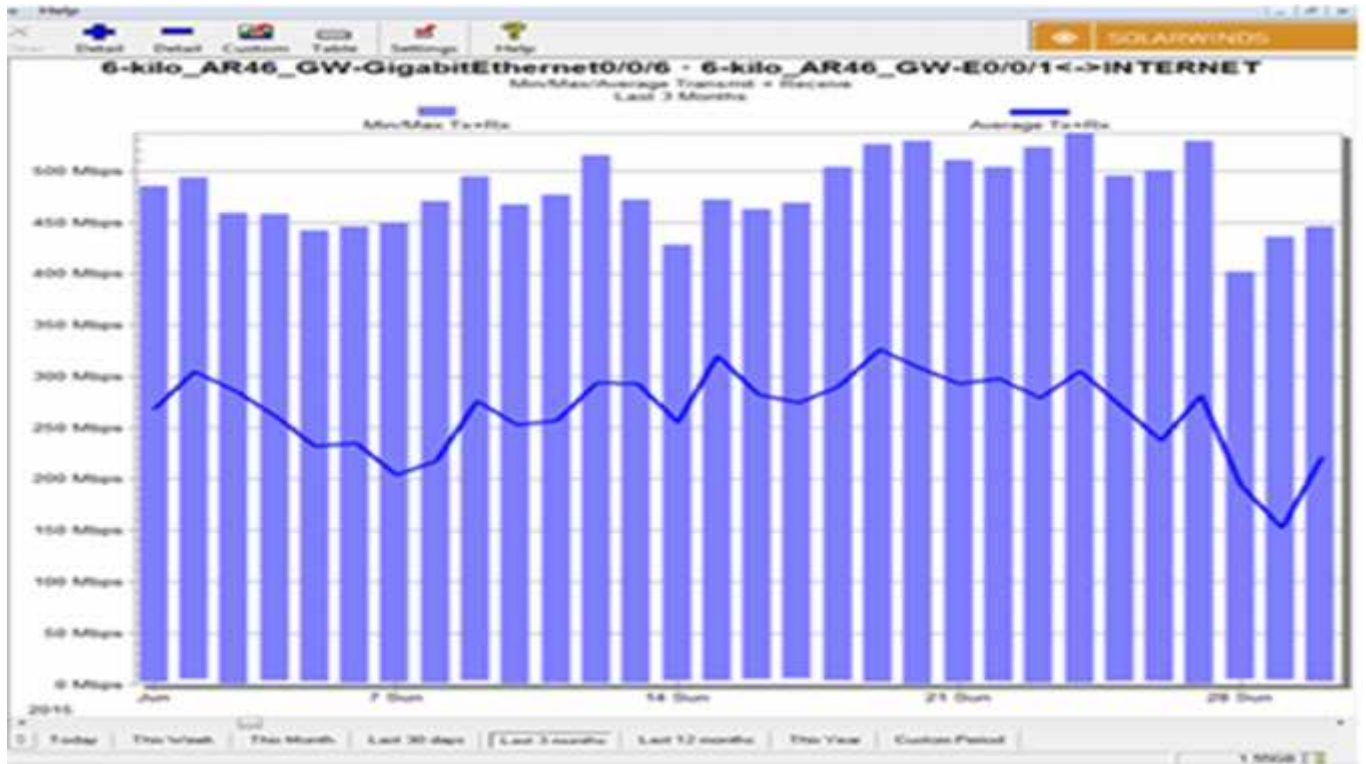


Figure 4.2 Minimum, maximum and Average data transmitted and received from 6kilo main router in June

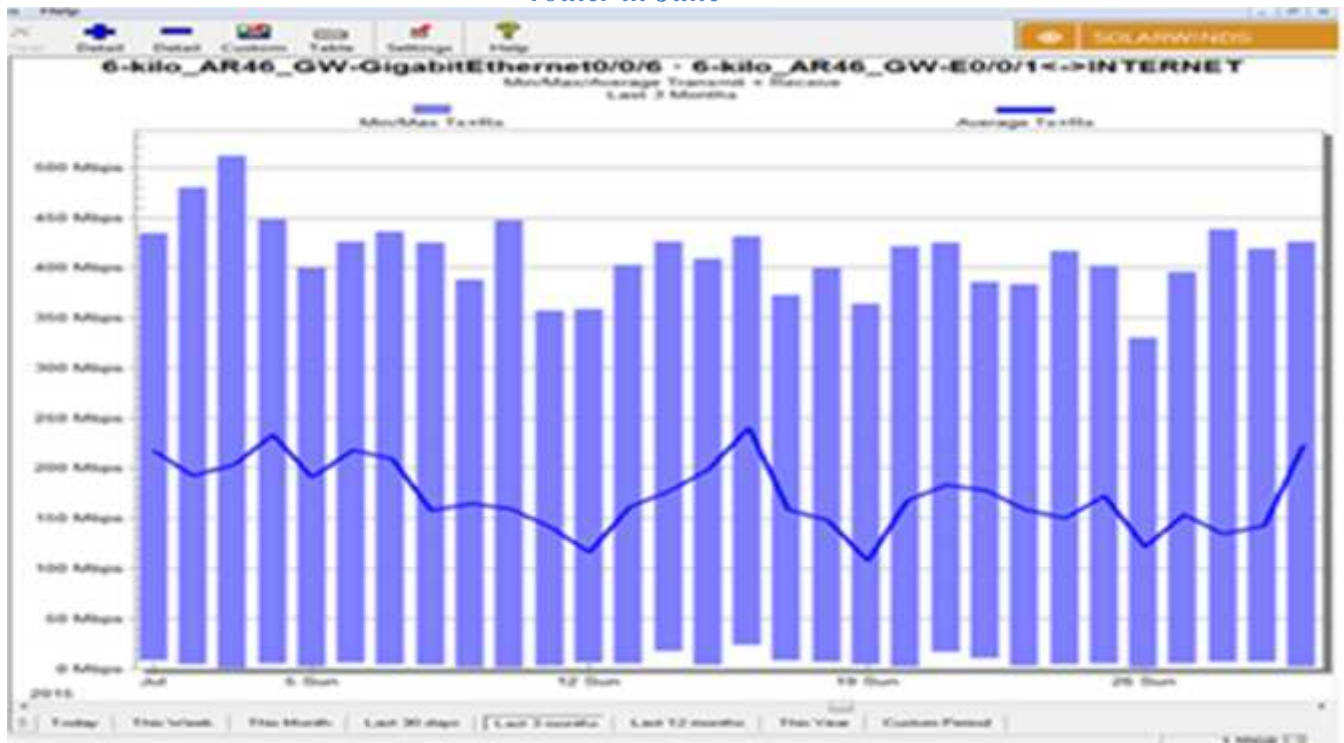


Figure 4.3 Minimum, maximum and Average data transmitted and received from 6kilo main router in July

Week	June		Percent utilization				July		Percent utilization	
	Max	Min	Max	Min	Max	Min	Max	Min		
1	496mbs(Jun2)	448mbs(Jun)	124%	112%	510mbs(Jul 3)	400mbs(July5)	127.5%	100%		
2	520mbs(Jun12)	423mbs(Jun14)	130%	105.8%	449mbs(Jul10)	352mbs(Jul11)	112.3%	88%		
3	546mbs(Jun20)	460mbs(Jun16)	136.5%	115%	430mbs(Jul16)	360mbs(Jul19)	107.5%	90%		
4	550mbs(Jun24)	400mbs(Jun28)	137.5%	100%	420mbs9Jul21)	333mbs(Jul26)	105%	83.3%		

Table 4.2 Minimum, maximum and average data transmitted and received from 6kilo main router

The table shows the data recorded in each week of both June and July. When we look at the June month the highest maximum bandwidth utilization of the weeks was seen in the 4th week of June 24 that is 550mb/s with around 137.5% percent utilization. The minimum bandwidth utilization was recorded on the same week on June 28. That is 400mb/s with around 100% percent utilization.

From July month, the highest bandwidth utilization was obtained in the first week of the month July3 that is 510mbs with around 127.5% percent utilization. The minimum bandwidth utilization was recorded on the 4th week on July 26, around 333mb/s with around 83.3% percent utilization.

4.2 Data Collected from the Core Switch

Switches create a virtual circuit between two connected devices, establishing a dedicated communication path between two devices. Switches on the network provide micro-segmentation. This allows maximum utilization of the available bandwidth. Figure 4.4 shows the data recorded from AAU core switch.

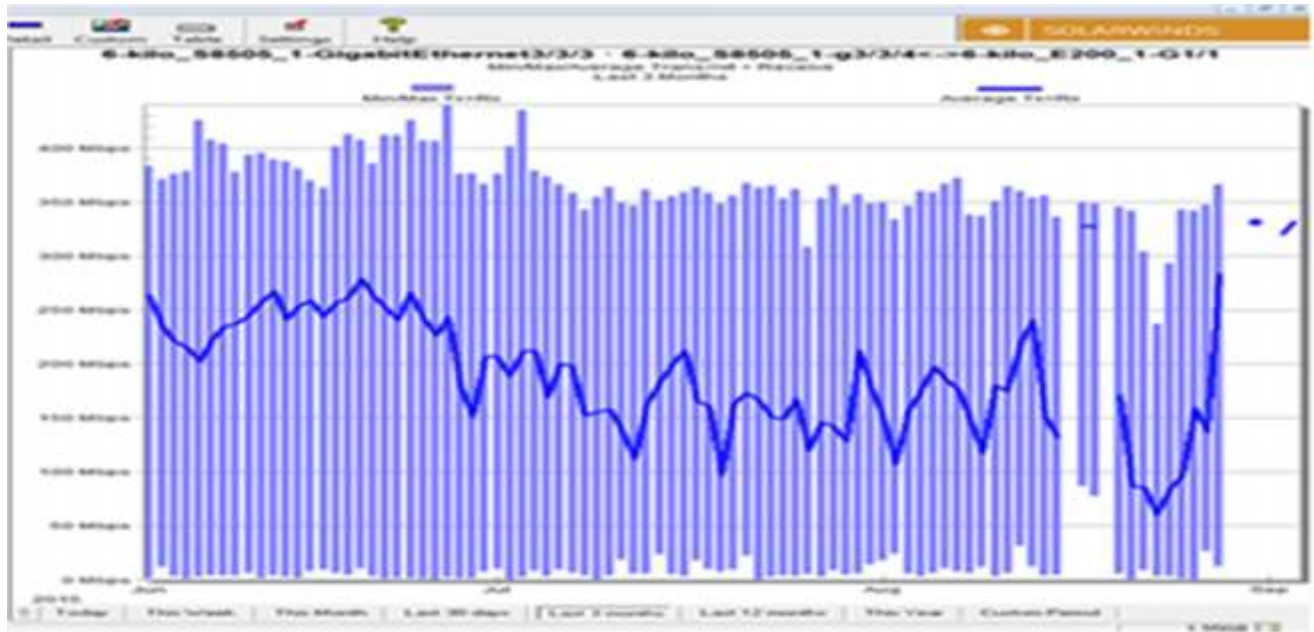


Figure 4.4 Minimum, maximum and Average data transmitted and received from 6kilo core switch within two months

Months data recorded	Maximum	Minimum	Percent utilization	
			Max	Min
June	June 27 440mbs	June 17 365mbs	110%	91.3%
July	July 3 435mbs	July 26 310mbs	108.8%	77.5%

Table4.3Minimum, maximum and Average data transmitted and received from 6kilo core switch

The table shows the data collected from 6kilo core Switch. We figure out the minimum, the maximum and average data transmit and receive. As shown in the above chart, the highest rate in June month was recorded on June 27. i.e. around 440mbps with 110% percent utilization. The minimum rate during this month was on June 17 that is around 365mbs with a percent utilization of 91.3%. Starting from July the highest rate was on July 3 around 435mbs with percent utilization of 108.8%. The minimum data record during this month was on July 26, 310mbs with percent utilization of 77.5%.



Figure 4.5 Weekly Minimum, maximum and Average data transmitted and received from 6kilo Core switch in June



Figure 4.6 Weekly Minimum, maximum and Average data transmitted and received from 6kilo Core switch in July

Week	June		Percent utilization		July		Percent utilization	
	Max	Min	Max	Min	Max	Min	Max	Min
1	425mbs(Jun7)	373mbs(Jun4)	106.3%	93.3%	435mbs(Jul 3)	375mbs(July1)	108.8%	93.8%
2	405mbs(Jun8)	380mbs(Jun10)	101.3%	95%	365mbs(Jul6)	343mbs(Jul8)	91.25%	85.8%
3	415mbs(Jun19)	365mbs(Jun17)	103.8%	91.3%	360mbs(Jul13)	350mbs(Jul19)	90%	87.5%
4	440mbs(Jun27)	370mbs(Jun30)	110%	92.5%	370mbs(Jul21)	310mbs(Jul26)	92.5%	77.5%

Table 4.4 Weekly Minimum, maximum and Average data transmitted and received from 6kilo Core switch

The chart shows the data recorded in each week of both June and July. The maximum bandwidth utilization of the weeks in June was on the 4th week on June 27, which is 440mbs with 110% of percent utilization. The minimum bandwidth utilization was recorded on the third week on June 17 that is 365mb/s with around 91.3 % of percent utilization. From the data recorded of the weeks in July, the highest bandwidth utilization was in the 1st week on July 3. That is 435mb/s with around 108.8% of percent utilization. The minimum bandwidth utilization was in the 4th week on July 26 that is around 310mb/s with around 77.5% of percent utilization.

4.3 Data collected from the Firewall

Firewall isolates organization's internal net from larger Internet, allowing some packets to pass and blocking others. Firewall can be employed to filter incoming or outgoing traffic based on a predefined set of policies.

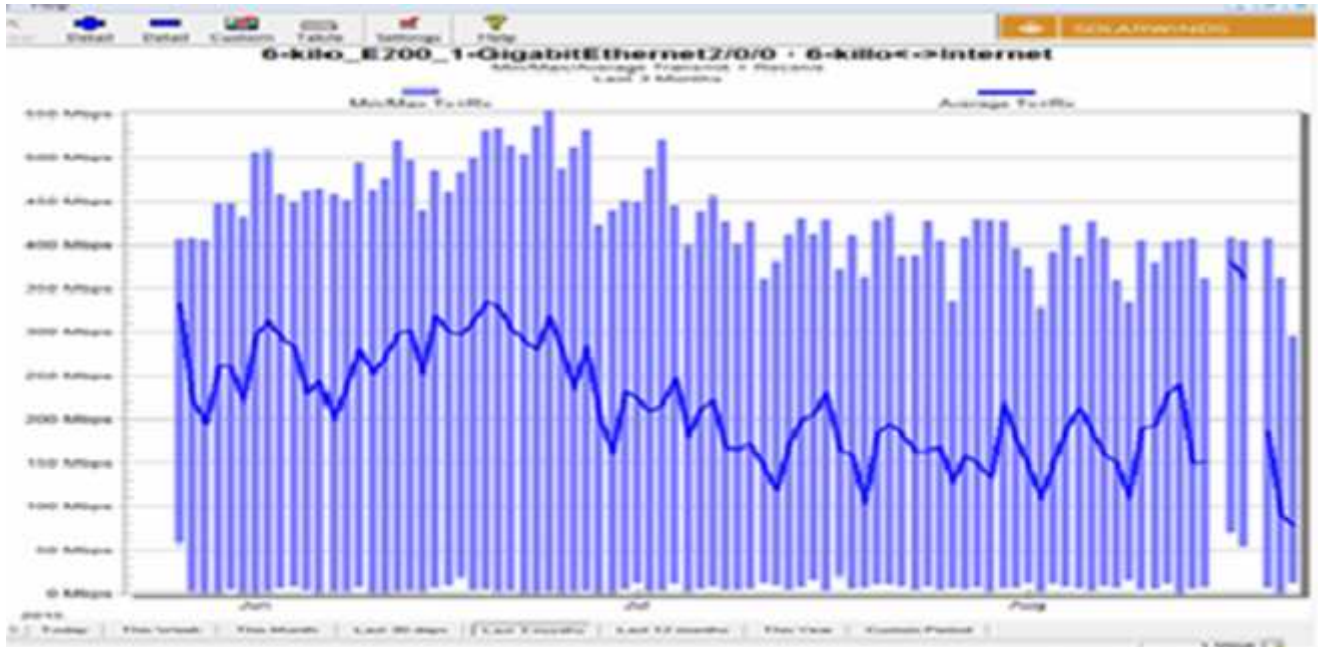


Figure 4.7 Minimum, maximum and Average data transmitted and received from 6kilo Firewall within two months

Months	Maximum	Minimum	Percent utilization	
			Max	Min
June	June 24 553mbs	June 28 420mbs	138.3%	105%
July	July3 520mbs	July26 348mbs	130%	87%

Table 4.5 Minimum, maximum and Average data transmitted and received from 6kilo Firewall

As described in the above figure, the data from 6 kilo firewall collected at the same time as that of the core switch and router. The maximum bandwidth utilization discovered from this machine in June was on June 24. It is around 553mbps with 138.3% percent utilization. And minimum rate during this month was on June 28, 420mbps with 105% percent utilization. Starting from July the

highest bandwidth rate was on July3. That is around 520mbs with percent utilization of 130%. The minimum record during this month was on July26, 348mbs with 87% percent utilization.

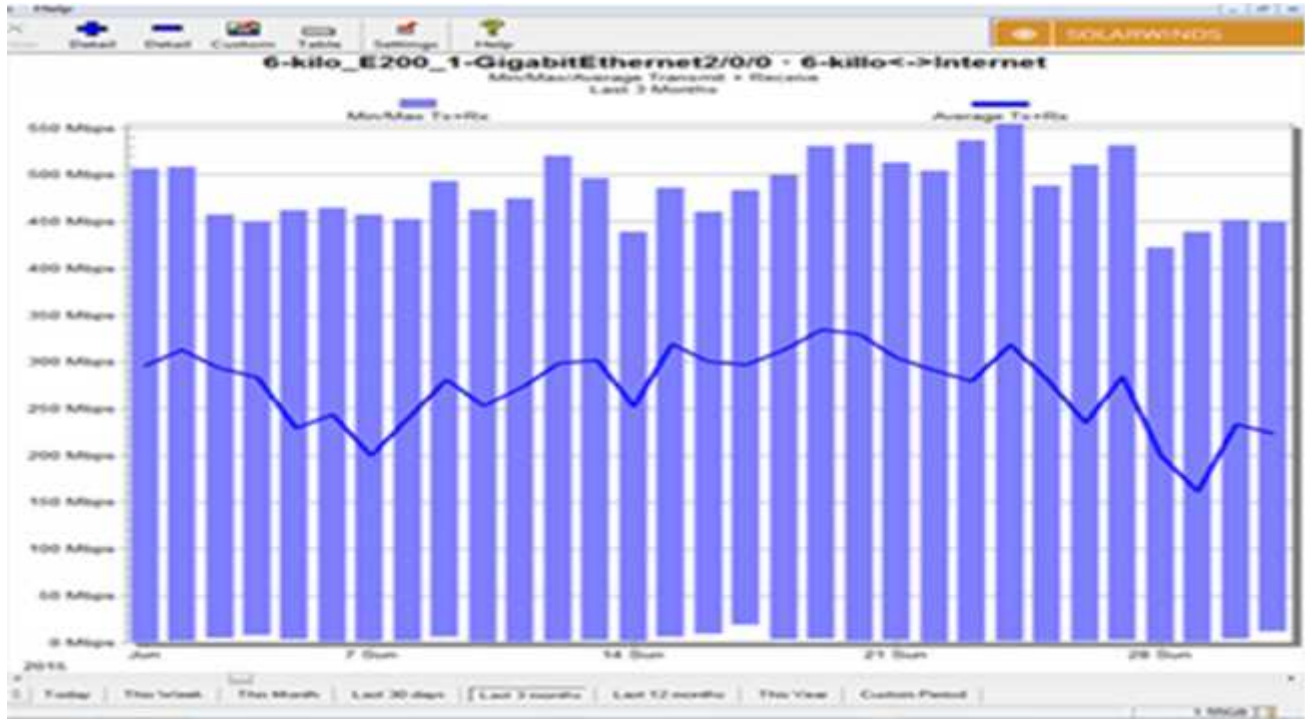


Figure 4.8 Minimum, maximum and Average data transmitted and received from 6kilo Firewall in June

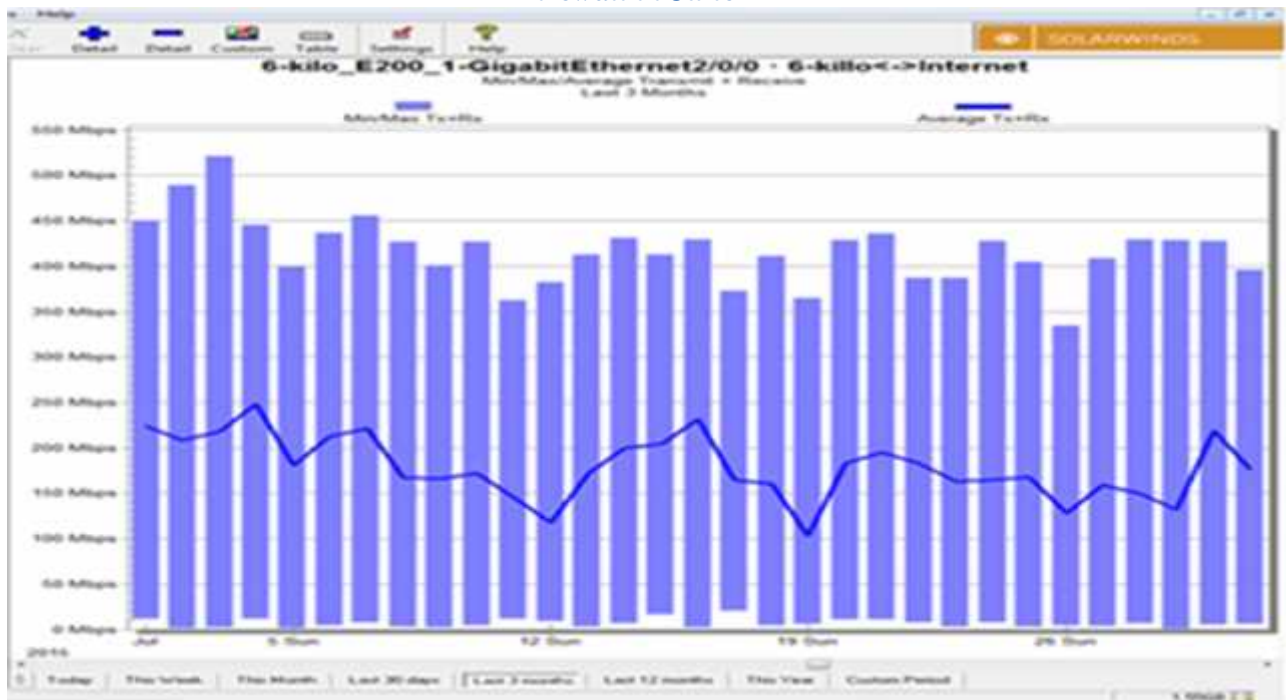


Figure 4.9 Minimum, maximum and Average data transmitted and received from 6kilo Firewall in July

Week	June		Percent utilization				July		Percent utilization	
	Max	Min	Max	Min	Max	Min	Max	Min		
1	510mbs(Jun2)	450mbs(Jun10)	127.5%	112.5%	520mbs(Jul 3)	400mbs(Jul5)	130%	100%		
2	520mbs(Jun12)	448mbs(Jun14)	130%	112%	457mbs(Jul7)	360mbs(Jul11)	114.3%	90%		
3	530mbs(Jun20)	460mbs(Jun16)	132.5%	115%	430mbs(Jul14)	365mbs(Jul17)	107.5%	91.3%		
4	553mbs(Jun24)	420mbs(Jun28)	138.3%	105%	440mbs(Jul21)	330mbs(Jul26)	110%	82.5%		

Table 4.6 Minimum, maximum and Average data transmitted and received from 6kilo Firewall

The above table shows the data recorded in each week of both June and July. On June, the maximum bandwidth utilization of the weeks was in the 4th week on June24. That is 553mbs with around 138.3% percent utilization. The minimum bandwidth utilization was in the third week June28, 420mb/s with around 105% percent utilization. From the weeks data collected of July, the maximum bandwidth utilization was in the 1st week on July3. That is 520mb/s with 130% percent utilization. The minimum bandwidth utilization was in the fourth week on July26, 330mb/s with 110% percent utilization.

4.4 Interview

The ICT expert has been interviewed to obtain detail information about the AAU network barriers. Network usage in AAU has some barriers, among them bandwidth utilization is the major one. This is because the university is not using its bandwidth in a manageable way and there are so many factors affecting bandwidth utilization including:

- Outdated devices,
- Old infrastructure,
- Users exponentially increasing from time to time,
- Unnecessary traffic on the network without filtering,
- Dynamic environment (users in a university is constantly changing), and
- The service from ISP varies.

These are some of the factors that affect bandwidth utilization in AAU and needs to be solved by managing the bandwidth and improving the infrastructure. Until now the university is not managing its bandwidth because of:

- Limited resources; this include human and hardware and software resources. The university has shortage of staffs to assign on bandwidth management and related fields. Limited hardware and software resource is another problem. Devices for managing bandwidth is not easily available and licensed softwares need high cost
- There is no rule or policy prepared for bandwidth management in the university
- Knowledge gap is also one of the major problems not having bandwidth management in AAU.

4.5 Analysis Summary

The explosive growth in internet and intranet deployment for a consistently growing variety of applications has created a massive increase in demand of high bandwidth. The bandwidth performance can predicate quality of service by managing different networks. There is a need of measurement for the new technology that will support the fast growing internet need. Effective tools must be there for the configuration protocols for monitoring network utilization and performance. In this experiment the minimum and maximum measurement bandwidth utilization with the percent utilization is taken from the main router, core switch, and firewall of AAU 6kilo data center.

From the experiment result of the router on June month the highest rate bandwidth utilization was on June 24, 2015, 550mbps with 137.5% percent utilization. The minimum bandwidth utilization rate scored on June 28, which was 400 mbps with 100% percent utilization. And on July, the highest bandwidth utilization scored on July 3, 2015. That is around 510mbps with 127.5% of percent utilization. The minimum bandwidth utilization rate was on July 26 that is around 333mbps with 77.5% of percent utilization. Among the two month data collected, the maximum bandwidth utilization was scored on June and the minimum bandwidth utilization was scored on July due to the user's experience. On June, there were high internet users from student and instructors. So as per the user, the bandwidth consumption was very high as the ICT expert stated.

When we see the data collected from the Firewall, it was same time the bandwidth utilization recorded high as that of the router. That is the maximum bandwidth utilization which was about 553 mbps with 138.3% of percent utilization scored on June 24. And the minimum bandwidth utilization was scored on June 28, 420mbps with 105% of percent utilization. Also during the

July month the highest bandwidth utilization was scored on July3 that is about 520 mbps with 130% percent utilization. And the minimum bandwidth utilization was scored on July 26 that is around 348mbps with around 87% of percent utilization. Among the two months, on June the maximum bandwidth utilization scored with the same day recorded from the router.

From the experiment result of the core switch the maximum bandwidth utilization which is about 440mbps with 110% percent utilization was scored on June 27. And the minimum bandwidth utilization was scored on June17, which was about 365 mbps with 91.3% of percent utilization. And during the July month the highest bandwidth utilization was scored on July3 that is about 435 mbps with 108.8% of percent utilization. And the minimum bandwidth utilization was scored on July 26 that is around 310mbps with around 77.5 % of percent utilization. This is the same with that of the router and the firewall.

The researcher discovered Percent utilization of the network. Percent utilization means capacity utilization. It shows how much of the available network bandwidth has been used. In this case, the researcher discovered percent utilization of AAU network. That is, from the available network bandwidth in the University how much of it is utilized.

The maximum and minimum data transmitted and received shows how the network bandwidth is utilized. The maximum data shows the highest network bandwidth usage and the minimum data indicates the minimum usage of bandwidth. Most of the time there is a high bandwidth demand than the available as we can understand from the graph.

There is a need of high bandwidth during June recorded up to 550mbps, which is beyond the available bandwidth in the university. This shows the University should control the bandwidth usage and the overall network flow.

One of the methods to control bandwidth usage is managing the bandwidth utilization. In this research the researcher developed a method of managing bandwidth by developing bandwidth optimization model in AAU.

4.5 Squid Analysis Report Generator (SARG)

The analysis done from SARG report is based on bandwidth usage of each of the three campuses of AAU (6kilo, 5kilo and 4kilo). Hence, the data is taken from two months, June and July considering a three day of data records from two machines of each campus for each month. The researcher took the highest and the lowest bandwidth usage of each campus within three days

from each month using the IP address of the user of the university network. The researcher also considered the working day and weekend time, so from three days data taking, one is from weekend time. This is because to consider different data records within working time and leisure time.

From June, the highest bandwidth usage was May31- June01 on working day. From this, the highest bandwidth usage of 6kilocampus was 9.36G by a machine with an IP address of [10.6.29.82](#) and the lowest usage was 0G used by a machine with [10.6.14.31](#) IP address. This indicates, the user was trying to access the network but can't get connected. Such problem may happen when network server is down because of power and it takes time to restart its service. Also sometimes the network may be down relating to ISPs' problem. The highest bandwidth usage of 5kilo campus was 26.74G by a machine with an IP address of [10.5.56.214](#) and the lowest was same as that of 6kilo campus 0G by a machine with IP address of [10.5.12.208](#). The highest bandwidth usage of 4kilo campus was 7.60G and the lowest was 0G by a machine with IP address of [10.4.16.62](#).

The lowest bandwidth usage record of June was on 25June on working day. From this record, the highest usage in 6kilo was 497.89M with an IP address of [10.6.61.30](#) and the lowest was 14B with an IP address of [10.6.20.8](#). The highest usage with the same month in 5kilo was 1.90G with an IP address of [10.5.25.68](#) and the lowest was 279B with an IP address of [10.5.39.102](#). The highest usage in 4kilo was 2.91G with an IP address of [10.4.40.119](#) and the lowest was 14B with an IP address of [10.4.19.33](#).

The highest bandwidth usage data recorded in June on weekend was June27. The highest bandwidth usage of 6kilo on weekends was 13.16G by a user with an IP address of [10.6.43.111](#) and the lowest was 0G by a user with [10.6.13.65](#) IP address. At 5kilo the highest bandwidth usage in this weekend was 12.44G accessed by a user with [10.5.42.101](#) IP address and 0G was the lowest in this campus. At 4kilo the highest bandwidth usage was 5.14G by a user [10.4.35.23](#) IP address and the lowest was 0G by [10.4.15.90](#) IP address.

The lowest bandwidth usage in June on weekend was June 28. Here, the highest bandwidth usage of 6kilo was 8.87G by a user with an IP address of [10.6.25.39](#) and the lowest 0G by a user with [10.6.25.72](#) IP address. The highest usage in 5kilo was 6.30G by a user with [10.5.35.151](#) IP address and the lowest was 70B by a user with an IP address of [10.5.24.117](#). The highest

bandwidth usage in 4kilo was 4.15G by a user with an IP address of [10.4.40.100](#) and the lowest was 24B by a user with an IP address of [10.4.21.65](#).

From July, the highest bandwidth usage data recorded on working day was on July06. Here, the highest bandwidth usage of 6kilo was 4.26 G by a user with [10.6.64.153](#) IP address and the lowest 0G by [10.6.14.142](#) IP address. The highest usage in 5kilo was 17.48G by [10.5.35.122](#) IP address and the lowest 0G by [10.5.11.190](#) IP address. The highest bandwidth usage in 4kilo was 7.29G by [10.4.91.74](#) IP address and the lowest was 0G by [10.4.16.194](#).

The lowest bandwidth record from July on working day was on 20July. From this, the highest usage of 6kilo was 707.60M by a user with [10.6.66.122](#) IP address and the lowest was 54B by [10.6.29.57](#) IP user. At 5kilo the highest usage was 352.82M by a user with an IP address of [10.5.25.103](#) and the lowest was 559B by a user with an IP address of [10.5.24.120](#) . At 4kilo the highest usage was 784.24M by a user with an IP address; of [10.4.19.48](#) and the lowest was 0G by a user with [10.4.90.164](#) IP address.

The highest bandwidth usage on July on weekend was July04. From this, the highest usage of 6kilo campus was 12.65G with IP address of [10.6.14.234](#) and the lowest was 0G by a user with [10.6.34.160](#) IP address. The highest usage in 5kilo was 7.88G by a user with [10.5.42.150](#) IP address and the lowest was 251B accessed by [10.5.55.82](#) . The highest usage in 4kilo was 13.79G accessed by a machine with IP address of [10.4.40.192](#) and the lowest was 0G by a user with [10.4.18.44](#) IP address.

The lowest usage on the weekend of July was on July 05. From this record, the highest usage of 6kilo was 7.57G by a user with an IP of [10.6.62.193](#) and the lowest was 0G by a user [10.6.28.15](#) IP. At 5kilo, the highest usage on the same weekend was 19.27G by [10.5.35.100](#) IP user and the lowest was 0G by a user [10.5.11.190](#) IP address. At 4kilo, the highest usage was 14.67G by a user [10.4.40.192](#) IP address and the lowest was 0G by a user [10.4.91.199](#) IP address.

From the above explanation the researcher focused on maximum bandwidth usage, so we calculated the highest average bandwidth usage by adding the maximum usage and divided by number of devices that accessed the network from each campus within the two months of June and July:

$$6\text{kilo campus; } \underline{9.36\text{G}+13.16\text{G}+12.65\text{G}} = 11.7\text{G}$$

$$\text{5kilo campus; } \frac{26.74\text{G}+12.44\text{G}+7.88\text{G}}{3} = 15.69\text{G}$$

3

$$\text{4kilo campus; } \frac{7.60\text{G}+5.14\text{G}+13.79\text{G}}{3} = 8.84\text{G}$$

3

The data obtained shows that the highest bandwidth usage is in 5kilo campus. So there must be a mechanism to limit the network bandwidth usage in this campus or it will be better to directly connect this campus to internet service provider (ETC) to improve the University bandwidth.

4.7 Bandwidth Management scenarios for AAU Network Infrastructure

4.7.1 Purpose of bandwidth management

The purpose of bandwidth management is to ensure that the AAU Internet connection continues to effectively meet institutional needs, serve the University's academic mission and meet the needs of the campus community. Generally, it can be stated that the purpose is to measure, monitor and share the University's internet and network resources for the end user.

4.7.2 Bandwidth Tiers

To ensure that Internet bandwidth is available for all institutional needs, the ICT office has to install bandwidth management system. This bandwidth management system controls the Internet bandwidth to and from the University campus. The following are bandwidth tiers that have been considered as stated by ITU [35].

1. The traffic critical to maintain the University's Internet presence. This indicates the traffic to and from AAU, applications and the University maintained web and email servers.
2. Academic classified traffic. This includes academic web browsing, messaging, and collaboration traffic, and is primarily based on the access location (with academic buildings receiving priority). <256kbps
3. Non-academic traffic and video streaming. This includes non-academic web browsing, non-academic video and audio messaging and collaboration, video streaming and gaming traffic. 512 Kbps

4. Large file transfers and system updates. This includes large downloads through distribution networks, large web downloads and updates to operating systems and applications 2mbps
5. Peer-to-peer files sharing. Peer-to-peer file sharing is limited to a percentage of a user's available bandwidth and collectively to a percentage of the University's overall bandwidth. 3-5mbps

From the above all bandwidth tiers we focused on academic classified traffic. It focused on web browsing in the university.

4.8 Quota based bandwidth usage for AAU:

From the data retrieved from SARG, we discovered the number of users per a day. We then calculated the total bandwidth with number of user. And assigned a specific bandwidth for each user to make the bandwidth stable, effectively utilized and to avoid crowded network traffic. The following steps are used by the researcher to calculate bandwidth for number of user.

$$\text{Quota} = \frac{\text{Total bandwidth}}{\text{Number of users}}$$

So, the total bandwidth of AAU network is 400mbps.

And we calculated average number of users collected from SARG in June and July. By adding the maximum and minimum number of users in each month then divided to number of days.

That is: maximum number of users in June = 4171, minimum number of users =253 and the maximum number of users in July = 2436, minimum number of users in this month = 314

$$\begin{aligned} \text{So, } & \frac{4171 + 253 + 2436 + 314}{4} \\ & = \frac{7174}{4} \\ & = 1794 \text{ users} \end{aligned}$$

$$\begin{aligned} \text{So here, total bandwidth divide to number of users} &= \frac{400000\text{kbps}}{1794} \\ &= 223\text{kbps.} \end{aligned}$$

Here the result is 223kbps for each user and it is recommended to use <256kbps in academic institutions [36]. So we can assign 223kbps for each user in the university in order to make the bandwidth available for all users and to utilize efficiently and effectively. We recommended this for the university to avoid a biased network bandwidth that some users consume large amount of bandwidth while others remain with less bandwidth.

To execute this task a programming code can be developed, but it will be unnecessary as we can configure on the UTM (Unified Threat Management) machine. With the current AAU network to manage end users, a server can be used by installing applications. So the university can manage its users by grouping like, academic staff, students. As the number of users taken for this study is average, if a special case happened that needs to use the bandwidth, the ICT office of the university can limit some bandwidth from some vlans for immediate issues.

Conclusions and Recommendations

5.1 Conclusions

This research focused on developing an optimization model for bandwidth utilization based on network traffic analysis. For this study we took Addis Ababa University network infrastructure as a case for network traffic analysis. We used solarwinds online traffic analysis tool to collect the ingoing and outgoing network traffic data weekly and monthly. Using the tool, we collected, organized and then analyzed the online traffic data relating to bandwidth utilization. The analyzed data helps to investigate bandwidth problems in the university and to find methods to effectively utilize the subscribed bandwidth.

From Solarwinds, the highest network traffic recorded was in June with large number of users in the campus. From weekly records, there is maximum ingoing and outgoing online traffic in the 4th week of June reaching up to 550Mbps. The maximum ingoing and outgoing traffic in July recorded up to 510Mbps in the 1st week of the month. The online traffic data records differ from one device to another of the router, core switch and firewall. For instance, the above data is retrieved from the main router. From the core switch, the maximum traffic in June is 440Mbps and 435Mbps in July. Data from firewall shows the maximum record is 553Mbps and 520Mbps in July.

Obviously, the AAU network bandwidth does rarely meet the users' requirements. This can be seen from the result of the network traffic analyzer tool. The data recorded in June was the highest because regular students were there in the university and the lecturers were on their job in the campus as well. But during July, there was a decreasing bandwidth usage. This is because most of the staff and students left the institution for break.

Even though the bandwidth usage has been decreasing during summer, the result from the experiment analysis tool shows there is a need to increase the network bandwidth in order to meet the demand of the users.

In addition to this the number of students entering in the University is increasing year after year and needs better bandwidth management system to fulfill the interest of the users in the University. AAU bandwidth is affected with different factors like;

outdated devices, old infrastructure, unnecessary traffic over the network link and users increment. Shortage of resources like human power, hardware and software, absence of policy are the causes that make AAU not using bandwidth management.

We investigated the best solution for bandwidth problem in AAU. Bandwidth utilization within campus level has been discovered and network traffic analysis has been made as described in the above section. To overcome the unbalanced bandwidth problem, bandwidth quota has been done and this will improve the bandwidth for better utilization and increasing user satisfaction. In addition to this, as the ICT expert explained in detail, the network devices and the cabling system of AAU counted long years which highly affects the service and needs to be changed. If the university upgrades its network, it can use the proposed model in this research. That can help the university to manage the bandwidth usage in the campus successfully.

5.2 Recommendations

- This study focused on developing optimization model for bandwidth utilization based on network traffic analysis of AAU. Future works are recommended to develop a policy for managing bandwidth utilization for the university.
- This study is done by considering campus level data (the three campuses 6kilo, 5kilo and 4kilo) as we couldn't find data at department level. Future researchers may dwell on bandwidth management that considers department level bandwidth usage.
- This study focused on AAU network infrastructure. However, it would be interesting to see works done on other Ethiopian Universities to discover if there are some patterns of usage.
- This research considered the current network design and infrastructure of Addis Ababa University. In the future, there may be design change or some colleges may split. It might be interesting to consider such possible scenarios in future works.
- This study investigated a system that can restrict a user to use the university bandwidth in a limited way and this may not be enough for educational purposes. So, one can develop a system which can check that the bandwidth usage is for educational purpose or for other activities and give priority for such educational accesses as universities are educational institutes.
- The AAU ICT office should block bandwidth hungry applications mostly used for entertainment purposes or applications which contribute less for educational purposes unless additional bandwidth is secured.
- The AAU management should take a measure to separate bandwidth usage of technology campus (5kilo) from 6kilo network to avoid high bandwidth consumption as the highest bandwidth usage observed is from this campus.

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Appendix: VLAN design of AAU

VLAN's on DHCP Server		
VLAN's (10.6.*.*)	Locations	Physical Location
13	Information Communication & Technology Development Office	ICT Office
14	Administrator Building	Admin Building
15	New Registrar	Registrar Building
17	Institute of Ethiopian Studies	President Office Building
18	Graduate Office	Old Informatics SISA
19	Business Education and School of Information Science and Technology	Business Education
20	Kennedy Library	Kennedy Library
22	Faculty of LAW	LAW Building
23	Old Registrar	Old Registrar Office
24	Institute of Educational Research	IER Office
25	College of Social Science Graduate Library	NCR Building Ground floor
26	ELRC	ELRC
27	College of Social Science	NCR Building
28, 29	Institute of Language Studies	OCR Building
30	Faculty of Business Education Management Department	FBE
31	Faculty of Business Education Library	FBE
32	Faculty of Business Education Accounting Department	FBE
33		FBE
34	Faculty of Business Education Economics Department	FBE
35	Finance Office	Finance Building
36, 37, 38	Department of Journalism	Mandela Building

39		ICT
40		FBE
41		FBE
42		FBE
43		FBE
44		FBE
45		FBE
50	Kennedy Library Wireless Department	Kennedy Library Building
51	Printing Press, clinic, break	Press
60	Wireless network at Institute of Ethiopian Studies	President Office Building
61	Wireless network at Institute of Language Studies	OCR Building
62	Wireless network at College of Social Science	NCR Building
63	Wireless network at Kennedy Library	Kennedy Library Building
64	Wireless network at Mandela Building	Mandela Building
65	Wireless network at LAW Faculty	LAW Building
66	Wireless network at Graduate Office	Old Informatics SISA Building
67	Wireless network at Purchasing	Purchasing Department