



ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCE
SCHOOL OF INFORMATION SCIENCE

DESIGNING DYNAMIC BANDWIDTH ALLOCATION ALGORITHM:

THE CASE OF ADDIS ABABA UNIVERSITY NETWORK (AAUNet)

**A THESIS SUBMITTED TO COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCE
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE MASTER OF
SCIENCE IN INFORMATION SCIENCE**

By: Fekadu Mekonen

January 2018

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Declaration

I Fekadu Mekonen, Declare that the work presented in this thesis paper entitled “DESIGNING DYNAMIC BANDWIDTH ALLOCATION ALGORITHM: *THE CASE OF ADDIS ABABA UNIVERSITY NETWORK (AAUNet)*” is original work of mine. It is done and presented under the guidance of my advisor Dr. Workshet Lameneu. This thesis has not been presented for any scholastic achievement in the university and any other materials I used in this study are acknowledged.

Signature _____

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This thesis has been submitted for examination with my approval as university advisor.

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Date _____

Dr. Workshet Lameneu

Dedication

This thesis is dedicated to my lovely sister Shiwoket Mekonen. It is because of you I know what a mother love looks like. For that thank you very much and you have a very special place in my heart!

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It will be difficult to mention everyone who helped me to be where I am! Below are some of them that I couldn't pass by. *Jesus Christ* and His mother *Saint Marry*. Jesus Christ who iswell everything! Without him, my world of color quickly fades to a dull, boring grey. Thank you for letting me see the light on the other side of the hole during my darkest time and giving me the strength when I was so weak.

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List of Acronyms

CBQ	Class Based Queuing
CIR	Committed Information Rate
CR	Ceiling Rate
DBA	Dynamic Bandwidth Allocation
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
FIFO	First In First Out
FQ	Fair Queuing
FTP	File Transfer Protocol
GNS3	Graphical Network Simulator
GR	Guaranteed Rate
HTB	Hierarchical Token Bucket
HTTP	Hyper Text Transfer Protocol
ICMP	Internet Control Message Protocol
IIS	Internet Information Services
IMAP	Internet Message Access Protocol
IoT	Internet of Things
IP	Internet Protocol
ISP	Internet Service Provider
MIR	Maximal Information Rate
NAT	Network Address Translation
NDE	Netflow Data Export
NFS	Network File System
NMS	Network Management System
NPM	Network Performance Manager
P2P	Peer-to-Peer
POP3	Post Office Protocol
PQ	Priority Queue
PR	Priority Rate

PRTG	Paessler Router Traffic Grapher
QoS	Quality of Service
SAM	Server & Application Monitor
SNMP	Simple Network Management Protocol
TCP	Transmission Control Protocol
ttt	tele traffic tapper
UDP	User Datagram Protocol
UTM	Unified Threat Management
VLAN	Virtual Local Area Network
VoIP	Voice over IP
VPN	Virtual Private Network
WFQ	Weighted Fair Queuing

ABSTRACT

Addis Ababa University (AAU) needs the Internet for many activities including learning, teaching, and publication. To facilitate those activities the university community uses different applications on Internet. Each applications have different bandwidth requirements, some of which are bandwidth greedy. Student also uses those application to access different resources on Internet. High student enrolments less supervised and more freedom of time to surf on Internet creates a high bandwidth demand and contribute to the slowness of the Internet connection making it ineffective to access academic resources. This is particularly true in academic institutes in developing countries. Instead of optimizing the existing bandwidth those Institutes responds to a slow Internet connection by adding more bandwidth which is uneconomical and a temporary solution. Addis Ababa University is not different from this scenario. This study was undertaken to find a way of allocating a decent amount of bandwidth to users. Dynamic bandwidth allocation algorithm was developed, in particular, an algorithm that allocates bandwidth based on user demand and bandwidth sharing. The prototype was developed to evaluate the algorithm and the requirements for algorithm development was collected from Addis Ababa University's main campus network gateway using purposive sampling. The prototype was evaluated on simulated environment.

Based on the Proxy logs statistics, there are unbalanced usage of Internet between users in the university. The result has shown that 2.7% of the Internet was used only by 10 users and most of those users generate a network traffic of 28GB and above in a single day with the highest of 42.92GB and a total of 298.31 GB of data, which requires for bandwidth management.

To solve an unbalanced usage of Internet bandwidth, a dynamic bandwidth allocation algorithm was designed which classify users into different classes and assigned bandwidth for the class. The users in that specific class inherit the allocated bandwidth rate, with the option of extended the limit of usage if there is a bandwidth in the bucket. The algorithm also guarantee minimum bandwidth rate for every users who joins the network.

Keyword: Dynamic Bandwidth allocation, Bandwidth Sharing, and network traffic analysis.

CHAPTER ONE

INTRODUCTION

1.1 Bandwidth Management

The campus-wide networking system is one of the essential asset for any university to support and deliver numerous key services. And it is going to be very difficult and not viable for higher education or research institutes to operate if it is not connected to the wider academic community [1]. Internet has become an essential component to access the outer world, to undertake and publish research works and therefore to attract funding [2].

A few decades ago the use of Internet was limited to kilobits per second, but the innovation of fiber cable changed it from kilobits to gigabits per second. The technological advancement, innovation of Internet-capable devices, and high-speed mobile networks make information accessibility limitless, but eventually there will be enough users with enough network activities to use up any network resources [3]. The Internet connectivity is readily available, carries many resources, and benefits the institution in many ways , but the organizations have realized that this connectivity also results in numerous unwanted side effects such as inevitable experience of network congestion caused by the flood of Internet Protocol (IP) traffic. Every organization has to deal with growing demands of their Internet infrastructure, especially higher education where there is a large number of users on daily bases. Managing this demand requires network infrastructure and bandwidth upgrade. However, this is costly and short-term solutions [4]. Therefore, effective Internet access requires an information delivery chain consisting of four essential links: (i) **content**, (ii) **connection**, (iii) **local resources**, and (iv) **bandwidth management** [2]. The

content must be user readable format, and the connection is crucial to access contents and resources over Internet or Intranet, local resources are more of infrastructure development that facilities resources accessibilities and contains resource that are accessed by users both local and external. But Bandwidth Management is the core element that requires much more attentions since the bandwidth that provide seamless flow of information over different media [5].

With the innovation of website, Internet has evolved from mere an information exchange system to a knowledge creation and dissemination platform [6]. The Internet is being viewed as a critical component of success by researchers, teachers, and students in a higher education system. And with wider Internet connectivity, educational institutions are beginning to tap the many opportunities offered by today's information societies. However, as pointed out by Kumar [1] the same connectivity also supports all sorts of applications and behaviors that consume bandwidth which frustrate users and ICT managers [7]. The IT managers dealing with network services within these institutions are very much concerned to make proper utilization of available network bandwidth and to make sure that sufficient bandwidth is available to every user for productive work. Among others, one way of providing sufficient bandwidth to users is by employing bandwidth management.

Bandwidth management requires three activities: Policy, Monitoring, and Implementation. These activities are interdependent with each other [8]. *Figure 1* shows the relationship between bandwidth management activities.

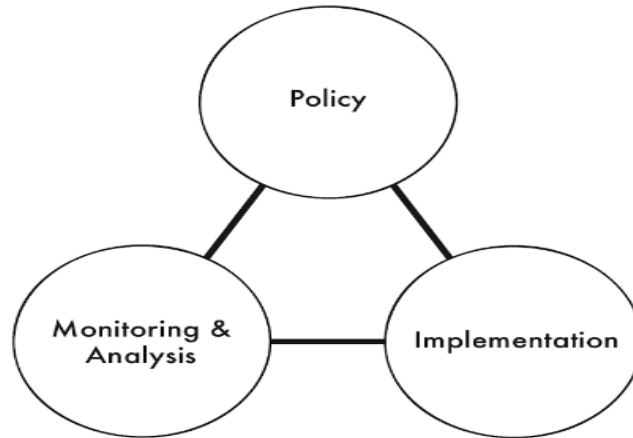


Figure [1]: The Critical Interdependent Components of Bandwidth Management [9]

- **Internet Usage policy** govern users to restrict which site and/or applications they are allowed to access through the network in timely manners.
- **Traffic evaluation and monitoring** are needed to cater new problems and develop a new algorithm for providing reliable services. In order to create a new algorithm, monitoring informs the process of creating an enforceable policy that reflects the actual needs of a user group.
- **Implementation** is down to the hardware and software that helps a network administrator to ensure that bandwidth is being managed properly and policy has adhered. As pointed out by Ashten [9], the key components of implementation are: (i) **Network analyzers**- for monitoring traffics. There are many network analyzers and since most of them are commercial, the main challenge of a network administrator is convincing the higher management to invest and budget approvals for a product to be deployed. With skilled man powers, there are a lot of open source software that used to monitor network: **Icinga 2, Nagios Core, Spiceworks** are a few to mention. (ii) **Firewalls** – for blocking malicious and unwanted traffic,(iii)**Anti-Virus** for protecting network,(iv) **Caches**- for efficiently using bandwidth,(v) **Traffic Shapers**—for prioritizing and controlling traffic; and (vi) **Quota Systems**—for managing user behavior

To sum it up, bandwidth management requires three activities, namely policy, monitoring, and implementation. If anyone of these are missing, then, management of bandwidth is significantly compromised [8] [10]. Since higher learning institutes are intensive user of the Internet, they require better bandwidth management system.

1.1.1 Addis Ababa University's Bandwidth and its Management Trend

AAUNet is a university-wide network that is designed to interconnect all campuses of Addis Ababa University. Currently the three campuses namely Sidist Kilo (Main Campus and Faculty of Business and Economics - FBE), Amist Kilo (Faculty of Technology and School of Pharmacy) and Arat Kilo (Faculty of Science) are interconnected with a state-of-the-art technology. Users from the indicated campuses get available services from the network: internet browsing, mail, software downloads digital library, dialup, and radio broadcast. IT penetration in AAU was generally categorized to be in a slow process. With this regard, the Systems Design and Data Processing Center (SDDPC), that was established in 1970 used to offer batch-oriented data processing services to the central administration in such application areas as, Payroll, General Ledger, etc. The center also provided services to student/staff researchers in analyzing survey results using statistical packages. However, dissatisfaction was indicated by the user community based on a survey conducted to determine the level of effectiveness of the center. Despite, SDDPC's long existence, no administrative unit was provided with on-line access facilities to any data maintained by the center. Despite the benefits of automation, IT had previously failed to entrench itself to any appreciable scale in AAU. In particular, the utilization of IT to support the administration (i.e, such applications as finance, personnel, student record, etc.) as well as the integration of ICT with the academic activities.

It is true that AAU had minimal e-mail connectivity mostly via FidoNet (through PADIS) for quite a while. Indeed, these have had great impact by virtue of their active roles in introducing (creating the awareness of) networks to the University community. In spite of this, however, many potential users and administrators do not seem to have been sensitized about networking services; others simply remain apathetic. Although with the introduction of the Internet in Ethiopia in 1997, the potential seems to be well recognized, the existing set up only tenuously establishes the network. In general, not only the usage, but also the capability of usage was very low. Very few staff members of AAU (mostly academic staff) were regular or occasional users and could be regarded as network aware. A substantial proportion of the staff had no network skills. However, there were some visible signs that indicated things are changing for the better. In view of the growing awareness of the important contribution the networking can make to the sharing of existing and scarce resources, various units started and continued making efforts to establish LANs. As the technology becomes more accessible and familiar, the demand for high quality services increased exponentially. Before such a critical mass of users was achieved, it is essential to have an appropriate infrastructure. There exists, therefore, a real need for improved and better organization of facilities and resources and making the network easier to use. For instance, rather than connecting from a PC and per faculty, arrangements to connect through a departmental LAN would allow the machines on the LAN to access the net [11].

As it is show below in figure 2 the university datacenter architecture is designed as collapsed core network architecture that consists of the core/distribution layer and access layer structure. The main campus network where the data was collected interconnects Addis Ababa Institute of Technology (AAiT), College of Natural and Computational Science (CNCS), Art school and school of Dental. The main data center hosts different server where many of the application is deployed, DMZ where the public facing domain is place and accessible by global user and the internal users which are major bandwidth user of the university.

training...etc [48]. Being the source of information, availability of bandwidth greedy application, online streaming, peer-2-peer sharing, increasing of student's enrollment and revolution of smart devices, the demand for bandwidth within institution, like Addis Ababa University, is on a constant rise that [12]and there will be no enough bandwidth that will support this demand.

The first response of System and Network Engineers for slow Internet connection is adding more bandwidth. Doing so is a tentative solution and costly. Adding more bandwidth without restriction push users to add more traffic on a network and fill the available bandwidth, which causes the overall available bandwidth to shrink and bring the bottleneck again. Therefore, if the connection is increased and bandwidth management system is not implemented, access to the Internet would decrease immediately and soon become impossible for users to access a basic resources like email [8].

For efficient use of the bandwidth, institutions have to use various techniques, technologies, tools, and policies. By efficient use means both the minimization of unnecessary bandwidth consumption and the delivery of the best possible levels of services to a user [13]. According to Aptivate in his bandwidth management work [14], managing bandwidth means removing unnecessary traffic such as music videos, entertainment movies, social medias at normal working hours which improves the performance of an Internet connection.

In addition to the reasons mentioned above, below are some factors that are considered for low bandwidth performance utilization [1]:

1. Students typically have more time, less supervised and under less pressure of work targets as compared to an employee. Therefore, university network is one of the most challenging

environments to manage where students have more curiosity to do experiments with existing network infrastructure and available services.

2. Different user's interest to use the Internet in different ways. Some users download music, movies, and use it for peer-to-peer sharing. It might not be bad if a user downloads music or favorite movies via peer-to-peer sharing, but if those non-academic sites consumes bandwidth and prevent researchers from accessing something useful resources on the Internet for their research or course works, it becomes problematic.
3. While trying to download movies or music on peer-2-peer site, it may lead them on dangerous site that invites viruses, worms, spyware which in turn chock the network bandwidth [15]]. In addition to this, a peer-to-peer (P2P) network applications are the most popular network among the student and is very high bandwidth consuming applications [16]
4. From service provider's perspectives, to save infrastructure costs and generate more profits, they usually use shared network system to deliver the bandwidth. The university must have a policy and system to verify if the service provider is lived up to its deal on providing the bandwidth they agreed upon.
5. Staff issues, without proper management, IT staff may themselves become a part of the problems, since the rules are at their hand and can manipulate as they wanted.
6. Little or no control and monitoring is implemented and then systems and network engineer make misinformed decisions about how much bandwidth is needed to upgrade, if necessary, without knowing if the existing bandwidth was being used for academic purpose.

In the digital world where everything is on the web, the primary responsibilities of the institutions are to provide an adequate amount of bandwidth for an efficient access of resources on the Internet to its user.

High enrollment of student over the years and shifting patterns of Internet usage creates administrative challenges for many universities [8].

There have been many algorithms to deal with these bandwidth utilization problems and still many researcher is attracted to this area! Hailay [17], developed a dynamic bandwidth allocation algorithm by classifying users into different class and allocate equal bandwidth to each user in the class. In his work, the following points are left out of considerations:

1. What if there is reserved bandwidth in the pool and users wanted to extend bandwidth utilization beyond the allocated rate?
2. User might have longer session without requesting bandwidth or requesting bandwidth with very limited rate, should the bandwidth stay allocated for a user who is not using it?
3. In equal bandwidth allocation, the subscribed bandwidth will support a certain number of users. How the algorithm is going to handle a new user with exhausted bandwidth?

In this thesis, the above points were taken into consideration while developing the dynamic bandwidth allocation algorithm. In order to design an efficient and cost-effective bandwidth allocation algorithm, below are the question that needed to be answered in this study

- What does AAUNet internet traffic looks like?
- What are the challenges of the University's Bandwidth utilization?
- What are the appropriate bandwidth allocation algorithms?
- What solution can be proposed in the form of algorithm?
- To what extent the algorithm efficiently and effectively manage bandwidth?

1.3 Objective of the Study

1.3.1 General objective

The general objective of this study is to design dynamic bandwidth allocation algorithm so that each user can have fair share of bandwidth usage.

1.3.2 Specific objectives

To achieve the desired general objective, this study deals with the following specific objectives:

- ✓ To select tools to capture data from the university network.
- ✓ To select tools to analyze both captured and offline data.
- ✓ To collect data using the selected tools.
- ✓ To select appropriate bandwidth allocation based university network traffic analysis
- ✓ To design dynamic bandwidth allocation algorithm for efficient utilization of the Internet.
- ✓ To evaluate the performance of the algorithm with prototype.

1.4 Scope of the Study

Due to the vast and complex nature of modern networking technologies [18], the depth of the problem coverage and financial limitation, the scope of this study is limited to developing dynamic bandwidth allocation algorithm for Addis Ababa University's network.

1.5 Significance of the Study

Ever since the innovation of World Wide Web (WWW) way of business operation is dynamically changed and the reliance of business operation on a network becomes critical [19]. While it brought a new information era and new ways of business operations, it also brings challenges along with it. Unbalanced usage of bandwidth between users is one of the many challenges that creates slowness in Internet connection. Network and system administrators have a challenging task of monitoring and analyzing user's traffic, identify potentially harmful and bandwidth greedy application, malicious, and

viruses that cchock the network. Therefore, dynamic bandwidth allocation algorithm makes easy the challenges faced by network and system administrator by allocating the minimum amount of bandwidth for each user and prevent them from using bandwidth more than what is allocated and it also gives priority to some users based on the rules and policy set. Apart from this, it can be a foundation point for other researchers who intend to continue their work in this area or other related areas like security audit or packet flow analysis.

1.6 Thesis Structure

This thesis is organized into six chapters. Chapter I introduces background of the study, describes statement of the problems, states questions that needs to be answered, define the objective, scope and significance of the study. Chapter II is devoted in reviewing different bandwidth management techniques and compares related work done by other researchers in the field. Chapter III focus on research methodology, data collection mechanism, and tools used. Chapter IV focuses on experimental data analysis and review bandwidth control concept. Chapter V demonstrates design and development of Dynamic bandwidth allocation algorithm and evaluating the prototype. Finally, chapter VI is devoted summarize the result, reveals the final findings, forwarding conclusion and point out the area for further studies.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1. Introduction

Back in the 80's when researcher began assembling the network of networks, Internet, there were no much-complicated applications and bandwidth management wasn't a concern. But in the 90's when WWW was invented by Tim Berners-Lee [20] the trend of business operation changes drastically and bandwidth is the core element for this operations. Bandwidth is expensive and limited and different applications requires different bandwidth amount. Managing client's traffic and keeping the bandwidth for production purpose becomes a challenging task for a network and system administrator [21].

The innovation of Network Address Translation(NAT) allows organizations to provide Internet to their employees using a shared media which makes the performance of Internet relies not only on a capacity of the link but also on the amount of traffic each user puts into the link. This means a single user running bandwidth greedy application such as torrent, online streaming, youtube can consume most of the bandwidth and starve other users on the link. According to Dhaini et al. [22], in order to get a decent and efficient amount of bandwidth on the shared network, a new method of packet handling should be implemented and they proposed a dynamic bandwidth management for a fair share of bandwidth among the users.

2.2. Network Traffic Analysis

Like any other resources, bandwidth is limited and from today's network of any type, Internet link will be used at least by more than one user and it requires to be shared with the user. The IT managers dealing with network services within these institutions and organization are very much concerned to make proper utilization of available network bandwidth and to make sure that sufficient bandwidth is available to

every user for productive work [1]. AAU is not different, with branch campuses and a large number of student and staff within the campus, leaving the bandwidth unallocated and unmanaged makes it difficult to get an accessible connectivity since certain users might consume most of the bandwidth with bandwidth greedy application. Network traffic analysis gives the network administrator the ability to identify which application is consuming bandwidth the most, at what time of the day is generated the highest hit, and then allows them to place a bandwidth limit per IP and per applications based on the priority of the application being used in the university [23]. This will ensure that Internet is being used for intended purposes or at least users use only allocated bandwidth for them.

Internet connectivity is very crucial for Higher Learning Institutions in order to fulfill their mandates of training, research, and consultancy. The Internet connection is important for (i) communication and collaboration, (ii) research and consultancy and (iii) courses and content delivery, i.e. academic management of courses and access to educational resources [4].

2.3. Bandwidth Management

Internet connectivity is increasingly becoming a strategic resource for university to make a greater use of the advantages offered by the advancement of communication technology to improve the provision and quality of the education [24], but the university is struggling to get a decent amount of bandwidth for learning, teaching, and publication due to unmanaged traffics. Managing bandwidth improves the performance of an Internet Connection by removing unnecessary traffic.

According to Kassim et al. [25] ever since the innovation of Internet Protocol (IP), Internet applications are growing faster and most communication network requires this application. Because of the growing needs, Internet network faces high traffic used from time to time. Rather than adding more expensive

resources only to get the same result, System and Network engineers must manage their bandwidth. Bandwidth management aims to improve the performance of the Internet connection by removing unnecessary traffic to have the right amount of bandwidth in the right place at the right time for the right set of users and application [1]. Bandwidth Management is a crucial tool for system and network engineers that are used to ensure enough bandwidth is available to meet the traffic needs of this mission-critical and time-sensitive application [64] [11].

There are two types of bandwidth management systems; static and dynamic, and static bandwidth management allocates a bandwidth in an arbitrary number of variable bitrate data streams, Dynamic bandwidth management on the other hand changes a bandwidth associated with a particular user overtime and traffic is shared or allocated on demand and distributes fairly between different users of that bandwidth.

A good bandwidth management technique should provide for bandwidth sharing so as to optimize bandwidth and reduced wastage. Dynamic bandwidth allocation takes advantage of server attributes of shared network [26]: (1) all users are typically not connected to the network at a time, (2) even when connected (in session), user is not transmitting packets at all times, and (3) most traffic occurs in bursts--there are gaps between packets of information that can be filled with other user traffic.

The crucial thing to notice about dynamic bandwidth management is that due to the constant user monitoring, the effect of the bandwidth management is always visible to the administrator [3]. If a user increases the amount of traffic sent then the algorithm will associate more network resources, provided that there is bandwidth, and if a user reduces the amount of traffic then the algorithm will reduce the amount of bandwidth that had been associated with that user.

Static bandwidth, in contrary, will not change associated bandwidth through time. The downfall of this approach is that, it is not scalable, that if a certain user is not using their share of bandwidth other needy users cannot access it, which leads a bandwidth wastage and congestion during peak hours [26]. The effects of the static bandwidth management are only evident if the user tries to use more bandwidth than currently allocated [27].

2.4. Bandwidth Usage Management Techniques

2.4.1 Introduction

Nowadays, almost every endeavor of human activities and daily lives depends primarily on computers and related devices which in turn are based on networks. For successful and cheap operation of those human daily activities in a computerized way, computer network plays a vital roles. Computer networks on its side, requires data bandwidth for its operation and functionalities. Bandwidth is a very essential but expensive network resources which must be properly managed to provide the maximum required throughput expected by the network owners and the network user. The lack of or improper management of a network to conserve bandwidth results to network crisis or failure

2.4.2 Optimization Technique

According to Ashton [9], there are two fundamental truth that characterized an enterprise network. The first of those fundamental truths is that an enterprise network brings indisputable value to the business of all types. Because of this business value, the amount of traffic that transits an enterprise network has historically increased at around thirty percent per year and the amount of traffic on the typical enterprise network is currently increasing at around 40-45% per year and double increase of the traffic every two years. The second fundamental truth that characterizes an enterprise network is that throwing bandwidth at performance problems, which will give a temporary solution until consumed by bandwidth aggressive

applications that are often less business critical application, will not be a viable solution. Rather than adding bandwidth for every performance problems, optimizing the existing bandwidth is the recommendations and best practice.

2.4.2.1 Traffic Management with QoS

Traffic Management refers to the ability of the network to provide preferential treatment to certain classes of traffic. It is required in those situations in which bandwidth is scarce, and there is one or more delay sensitive application, VoIP, business-critical applications that will not tolerate the slightest delay. Network administrator, while monitoring and shaping traffic should also perform preferential treatment on a certain application by limiting the bandwidth that certain applications should (such as email) receive while simultaneously ensuring fairness for all the users of some business critical, delay-sensitive application. One way to ensure fairness is to guarantee that all users receive at least a minimum amount (e.g., 100 Kbps) [28] of bandwidth whenever they are connected to the network and be able to access the basic resources on internet.

Another important factor in traffic management is the ability to effectively control inbound and outbound traffic. Queuing mechanisms control bandwidth leaving the network, but do not address traffic coming into the network, where the bottleneck usually occurs [9] [29].

2.4.2.1 Caching

The current motivation for using caching is to both accelerate the delivery of content, as well as to optimize the use of bandwidth. Viewed this way, it is possible to think of caching as a technique in which storage resources are deployed in such a way to cause the network to perform as if it had received a bandwidth upgrade. Caching is often present in several forms within a corporate network. Most browsers contain a local cache for web pages they have already accessed. A proxy cache acts similar to a browser cache, but sits at the WAN edge and caches requests from many users, instead of just one. Data center

(or reverse proxy) caches offload servers and help speed content out of the data center. When referring to actively managing bandwidth, proxy caches are the type of caches that are used [29].

2.4.2.2 Compression

The basic function of compression is to reduce the size of data to be transmitted over a network without reducing the information content of the single. This can be accomplished with lossless data compression technique. It is possible to look at compression in a very similar way to caching and in order to get the optimal result of bandwidth management it is advisable to use compression in conjunction with traffic management [9].

2.4.3 Queuing and Scheduling Technique

Scheduling mechanisms employ different actions on different data packets in order to provide different levels of Quality of Service. It is a means of controlling the transmission of packets and therefore considered to have a great impact on the quality of service since it determines the sequence in which packets from different flows are processed. These mechanisms are also used to ensure that all packets are handled in a fair manner to prevent one user from utilizing more than his or her share of resources [21].

2.4.3.1 FIFO Queuing

First In First Out (*FIFO*) is the principle of a queue of first-come first-server behavior, what comes in first is handled first as it is shown in figure 3 below [30]. In a FIFO queue packets are treated the same and if a queue becomes congested incoming packets are dropped. The main advantage of FIFO queue is that it is simple and considered a good solution for software-based routers.

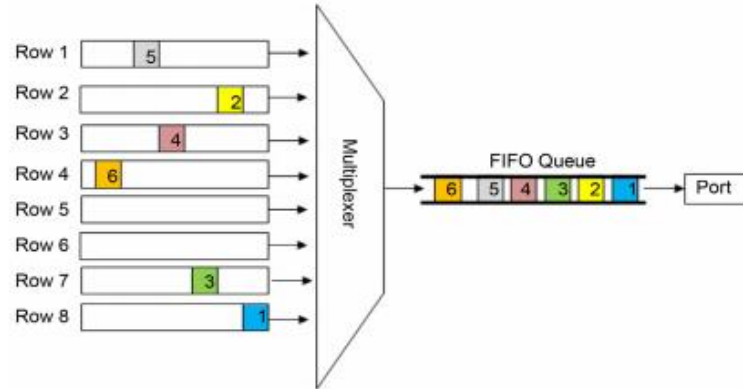


Figure [3] first-In, First-Out (FIFO) queuing

2.4.3.2 Priority queuing

Priority queue ensures that important traffic gets the fastest handling at each point where it is used. As shown in figure 4, it was designed to give strict priority to important traffic. Priority queue prioritizes according to packet source/destination, packet type, and packet label to discriminatively serve various traffic flows [31]. Priority queuing is the basis for a class of queue scheduling algorithms that are designed to provide a relatively simple method of supporting differentiated service classes. In a classic priority, queue packets are first classified by the system and then placed into different priority queues. Packets are scheduled from the head of the given queue only if all queues of higher priority are empty. Within each of the priority queues, packets are scheduled in FIFO order. Some of the priority queue benefits are relatively low computational load on the system and setting priorities so that real-time traffic gets priority over applications that do not operate in real time. If the volume of higher-priority traffic becomes excessive, lower priority traffic can be dropped as the buffer space allocated to low-priority queues starts to overflow. This could lead to complete resource starvation for lower priority traffic [32].

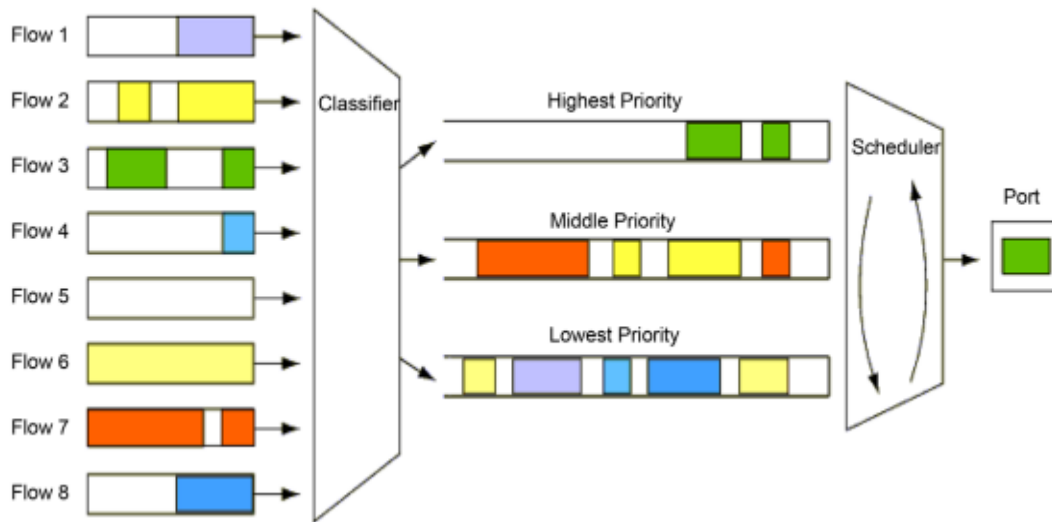


Figure [4] Priority Queuing

2.4.3.3 Fair Queuing

Fair Queuing (FQ) has been designed to avoid the problem of Priority Queue (PQ) discipline, where one flow can monopolize and use all the available bandwidth of the network and, hence, lead the lower priority flows to bandwidth starvation [33]. In FQ, arriving packets are classified into different flows and stored into a queue dedicated to that particular flow. The round-robin algorithm, is an algorithms that employed by process and network schedulers in computing and time quotas are assigned to each user without priory [34], is used to service all the queues so that queues are served in a fair way and one source cannot use more than its share of network bandwidth. Figure 5 illustrates an example of FQ. Each flow is redirected to its own queue. Queues are scheduled in round-robin way [31].

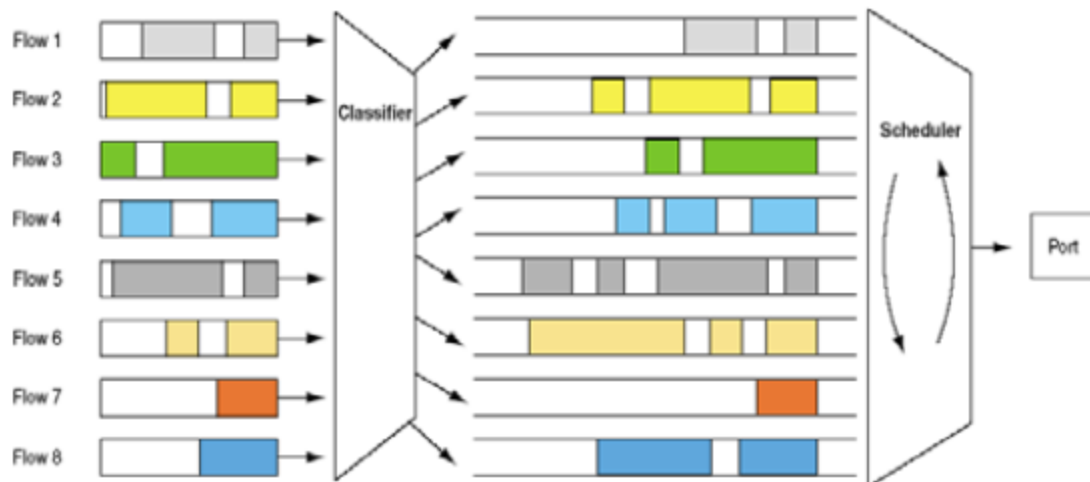


Figure [5] Fair Queuing

The main advantage of FQ is that bursty flows do not affect the overall performance. If a flow is too bursty, then only its queue will be filled up, without any interference with any other flow. The drawbacks of FQ are outlined as follows. The scheduler takes a packet at a time from each queue regardless of the packet length. For example, if a queue contains bigger packets than other queues, then that queue will use a larger portion of the total network bandwidth and it will take more time to be served. Furthermore, the FQ algorithm is more complicated than FIFO and PQ; hence a software implementation (the most common) may result in performance problems [35].

2.4.3.4 Weighted Fair Queuing (WFQ)

WFQ was introduced in 1989 by Zhang, and Schenke [36]. The algorithm provides fair output bandwidth sharing according to assigned weights. A Weighted fair queue is a variant of fair queue equipped with a weighted bandwidth allocation. The bandwidth allocation among packet queues involves not only the traffic discrimination but the weightings assigned to packet queues. In characteristics, weighting fair queue provides two important properties [37], 1) supporting effective QoS design: No occurrence of bandwidth starvation encountered usually in a Priority Queue, 2) Fairness of bandwidth sharing is ensured among admitted flows. Thus, in a weighted fair queue, traffic gets predictable service [31]. WFQ

offers fair queuing that divides the available bandwidth across queues of traffic based on weights. According to Dekkeris adn., Adomkus, T [38] each flow is associated with an independent queue assigned with a weight to ensure that important traffic gets higher priority over less important traffic. It supports flows with different bandwidth requirements by giving each queue a weight that assigns it a different percentage of output per bandwidth. WFQ also supports variable-length packets, so that flows with larger packets are not allocated more bandwidth than flows with smaller packets [32].

2.4.3.5 Class Based Queuing

This scheme puts packets in queues but guarantees a certain transmission rate. If a given queue has got no packets; its bandwidth is given to other queues. Therefore the scheme enables the network to cope with flows with considerably different bandwidth requirements by allocating a specific percentage of the link bandwidth to each queue. The main strength of class-based queuing is that there are no queues that experience bandwidth starvation since each class receives a certain amount of service for each round. Class-based queuing can be used to control the amount of bandwidth each service class can use and it is easily implemented in hardware. The downside of CBQ is that it only provides fair allocation if all the packets are of the same size [35]. If it happens that some queues contain larger packets they will end up utilizing all the bandwidth. Also in an effort to provide fairness, CBQ does not provide strict priority to the deserving traffic [29].

2.4.4 Traffic Shaping Techniques

2.4.4.1 The Leaky Bucket

The leaky bucket algorithm implements the traffic shaping when each host is connected to the network by an interface containing a leaky bucket which is a finite internal queue. It converts any incoming traffic into a smooth, regular stream of packets as it is shown in figure 6 below. A leaky bucket interface is connected between a packet transmitter and the network.

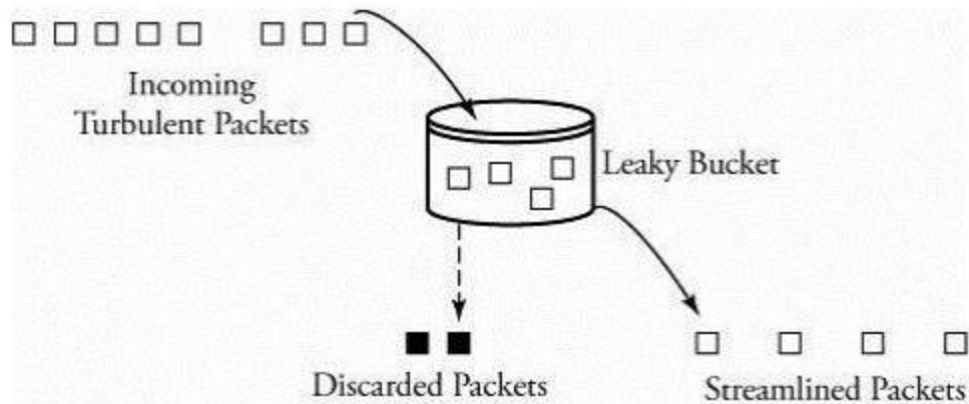


Figure [6] Leaky Bucket Traffic Shaping

At the heart of this technique is a finite queue. When a packet arrives, the interface decides whether that packet should be queued or discarded, depending on the capacity of the buffer. The number of packets that leave the interface depends on the protocol. The packet-departure rate expresses the specified behavior of traffic and makes the incoming bursts conform to this behavior. Incoming packets are discarded once the bucket becomes full [39].

2.5. Challenges to Effective Internet Access

Managing bandwidth improves the performance of an Internet connection by removing unnecessary traffic. Bandwidth is like a pipe. It doesn't matter how big the pipe is if the traffic in the pipe is not managed it will clog up with unwanted traffic and be hijacked by peer-to-peer traffic, viruses and other malware. A survey conducted by African Tertiary Institutions survey (ATICs) pointed out that [40]:

"...improving bandwidth management is probably the easiest way for universities to improve the quantity and quality of their bandwidth for educational purposes"².

² *African Tertiary Institutions Connectivity Survey (ATICS): Full Report*; Gakio; 2006.

Bandwidth management is essential for any institutional network. Universities understand that if they had a much smaller capacity connection and managed it correctly, the Internet would still be accessible. However, if the connection was increased and the management removed, user access to the Internet would decrease immediately and soon become impossible. According to Aptive [14], the main challenges relating to bandwidth management can be categorized as increasing awareness, improving skills and providing appropriate tools.

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 that should govern its use.

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 are not yet present, and if they are they may not be used to their full extent. Working with partner institutions, amongst others, Aptivate believed that further investigation would answer the remaining questions:

- Why are tools not being used at many institutions?
- Are the tools appropriate for the institution?
- 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?

2.6. Challenges to Bandwidth Management and Internet Access

It is tempting to think of bandwidth management as a technical issue requiring a technical solution. But this is not the case. Ensuring that bandwidth is available for users requires policy, resources, and commitment from all stakeholders. Although there are technical issues relating to bandwidth management, the biggest challenge is to raise awareness of the importance of managing bandwidth [14].

2.7. Related Works

In the last few years, several studies related to Dynamic Bandwidth Allocation (DBA) algorithm has been done [41] [42], [17], [43]. Below are some of related works for DBA algorithms on EPON and enterprise network. Jayakrishna et al. [44] proposed token based policing with *equal bandwidth* allocation for a set of flows. The token-based fair bandwidth allocation maintains multiple queues and per-flow information and seeks to allocate equal service time for each flow. In designing the algorithm, they didn't consider that different class of user requires different amount of bandwidth for different set of applications. Holstinger [18] discussed the problems that creates a congestion on the network link. They implement the policy mechanism that prevent congestion by ensuring that the traffic sources doesn't submit excessive traffic into the network. As it is discussed in the literature review, the outflow of leaky bucket is regulated at a constant rate no matter at what rate packets enter the traffic shaper. In today's network, a constant packet flow will not meet the demand of an application since applications requires different set of bandwidth. Alan [45] discussed the weighted Queuing algorithm for fair bandwidth allocation which is a simply allocating a buffer space fairly by dropping packet when necessary from the conversation with the largest queues. The work discussed in [17] has similar objectives to this thesis.

However, the proposed bandwidth allocation is equal to all users in the class in which individual traffic statistics are not taken into account in allocation procedure. Moreover, the allocation didn't consider the coming of new user after all the bandwidth exhausted. Using the server attribute and the dynamic bandwidth allocation characteristics [5] bandwidth is collected from unused bandwidth in the guaranteed bandwidth allocated to the users and since users access the resources on the Internet in burst, the algorithms collects those bandwidths into bucket and the algorithm keeps monitoring the availability of the bandwidth in the bucket. Minilik [46] had investigated the cause of the bandwidth shortage by analyzing the network performance and bandwidth utilization data to develop a suitable framework that improves the bandwidth usage.

In this thesis, the researcher proposed a class-based dynamic bandwidth allocation where user is given a guaranteed amount of bandwidth and has the ability to extend beyond the allocate bandwidth rate, should they need more bandwidth and if there is bandwidth in the pool. Another consideration is idle time calculation and bandwidth retrieval. If a user connection sessions are longer and no packet is requested in a given time, then the algorithm collect back the allocated bandwidth to the bucket so it can be extended to those who needs to access more bandwidth.

2.8. Summary

Different types of bandwidth allocation has been done and is still the hot area that attracts many researchers to find optimal bandwidth utilization. As it is indicated above in related work and in the literature review most of the researcher proposed different type of algorithms, but they left the considerations of individual traffic statistics that each user and applications require different set of bandwidth requirements. Some suggested dropping queued packets when the link gets congested and some proposed equal bandwidth allocations for each user. Neither dropping the packet when the line is

congested, nor equal bandwidth allocation will be a viable solution for today's network due to the reliance of today's businesses operation on Internet and the slightest delay or interruption of Internet has a negative consequence for its success. Since neither dropping nor equal bandwidth allocation is not the viable solutions, the researcher proposed the user demanded bandwidth allocation that every user can get a minimum amount of bandwidth that allows them to access basic downloads of email, and web surfing.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter is devoted to explaining methods that was followed by this study. It provides information on what methods used, why it was chosen, and proposed system. The offline proxy and web server logs used in this analysis are only eight days as it is only used to assess a user bandwidth consumption, duration of session and applications accessed.

3.2 Design Science

Research follows a stereotypical pattern and such uniformity makes it easier to recognize and evaluates the results of such research [47]. In this thesis, a design science approaches was used which is an outcome based information technology research methodology, which offers a specific guidelines for evaluation and iteration within the research.

Design science is knowledge in the form of constructs, techniques and methods, models, well developed theory for creating artifacts that satisfy given sets of functional requirements.

The design science research methods follows a model in creating the artifacts and its end result is knowledge creation [48].

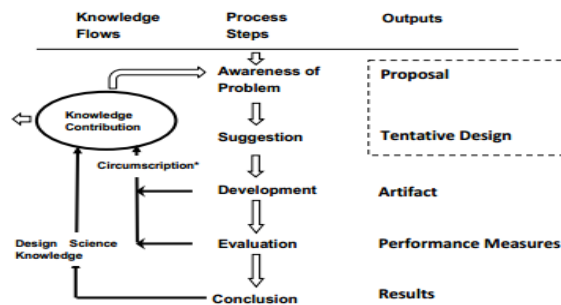


Figure [7] Design Science Research Process Model (DSR Cycle)

Awareness of Problem: an awareness of an interesting research problem may come from multiple sources, including new developments in industry or identification of problems within a reference discipline. Reading in an

allied discipline may also provide the opportunity for application of new findings to the researcher's field. The output of this phase is a Proposal, formal or informal, for a new research effort.

Suggestion: The Suggestion phase immediately follows the proposal and is intimately connected with the proposal developed based on the Awareness of a Problem

Development: The Tentative Design is further developed and implemented in this phase. The techniques for implementation will vary depending on the artifact to be created. An algorithm may require construction of a formal proof to show its correctness. An expert system embodying novel assumptions about human cognition in an area of interest will require software development, probably using a high-level package or tool.

Evaluation: Once constructed, the artifact is evaluated according to criteria that are always implicit and frequently made explicit in the Proposal (Awareness of Problem phase).

Conclusion: This phase could be just the end of a research cycle or is the finale of a specific research effort. The finale of a research effort is typically the result of satisficing, that is, though there are still deviations in the behavior of the artifact from the (multiple) revised hypothetical predictions; the results are adjudged "good enough."

3.3 Data source and Data Collecting Methods

Collecting and organizing data are an integral and critical part of the research process. Because improperly collected data has the following consequences [48].

- Inability to answer research questions accurately.
- Inability to repeat and validate the study.
- Distorted findings resulting in wasted resources.
- Misleading other researchers to pursue fruitless avenue of investigation

For this thesis, nonprobability sampling was used. Among the nonprobability sampling techniques, such as quota sampling, convenience sampling [49], and purposive sampling, particularly purposive sampling was chosen. The university network operates 24 hours a day and 7 days a week unless there is a power fluctuation or an Internet connection problem. To develop bandwidth allocation algorithm, a constant monitoring and analysis of user traffic is required to get detail information about a user behavior [50]. It

is not going to be economical to gather user traffic data for years continuously. Sampling is used to represent a data behavior of the population. In taking sampling, researcher must be careful otherwise the collected data may not answer the research questions or may be irrelevant to the study [51]. It will not be relevant to analyze the data that were only recorded during the night time where the socio-economic activities of university staff were almost none and the student's socio-economic activities were very limited or it will be irrelevant to infer decisions based on the data that was collected when the user population is less as compared to other time, for example, break time. So three months of live data was captured using SolarWinds from June to August 2016 when the internet subscription was 400 mbps and a three month of live data was captured using PRTG from January to March of 2017 when the Internet subscription was 1 Gbps and the data was collected using purposively sampling technique.

3.3.1 Data Collecting Tools

Different data collection tools were used in this study, below are the description why the tools has been chosen to collect the data.

3.3.1.1 Squid

Squid is a caching proxy for the Web supporting HTTP, HTTPS, and FTP. It reduces bandwidth and improves response times by caching and reusing frequently-requested web pages. Squid has extensive access controls and makes a great accelerator in server response. It also increase content delivery speeds to the clients. AAU University used a proxy server to accelerate the internet speed and block a certain site from being accessed by user even though currently they stopped using it. The proxy server keeps logs of each user's web request and provides a detail information about the user behavior related to bandwidth consumption, session duration, and source and destination IP address of user [52].

3.3.1.2 SolarWinds NPM

One of the most difficult and demanding tasks for a network administrator is keeping an eye on the network and monitoring its health, watching bandwidth usage, finding and identifying problems, and so

many other such tasks that require network administrator constantly running around, checking on the equipment and watching multiple monitoring applications. SolarWinds NPM [53] installed in data center to collect network performance statistics at Addis Ababa University main campus, such as the minimum and maximum data transmit rate, average transmit rate of Addis Ababa University network link.

3.3.1.3 PRTG Network Monitoring Tools

PRTG Network Monitor allows system administrator to monitor the network performance, and bandwidth utilizations through SNMP and WMI protocols [54]. PRTG software was installed in the data center of Addis Ababa University main campus to collect data related to the network performance.

3.3.2 Data Analysis Tools

To develop user demand dynamic bandwidth allocation algorithm the requirements were gathered from Addis Ababa University Main campus network traffic. Total of Six months of network traffic was captured using SolarWinds and PRTG network monitoring software. When the Internet subscription was 400 Mbps a three months of data was capture using solarwinds and when the subscription rate was upgraded to 1Gbps, a three months of data was collected to compare the data transmit between the two periods. A three month of offline data, proxy logs and web logs, also analyzed using log analyzer software in order to evaluate user bandwidth utilization rate, to identify the application that consumes bandwidth the most [55].

3.3.2.1 SolarWinds and PRTG

The main challenge of any network administrator is to identify the root cause of the network bottleneck before the network service outage occurred. Both SolarWinds [53] and Paessler Router Traffic Grapher (PRTG) network monitoring software have the abilities to detect the network failure symptoms, monitor the network performance by application, Protocols and IP groups. In order to analyze the network performance of the university, to measure if the subscribed bandwidth is being utilized fully [54], a three

months data was gathered using SolarWinds from June to August of 2016 and using PRTG from January to March of 2017 continuously at Main campus's gateway with different bandwidth subscription rate.

3.3.2.2 SAWMILL

SolarWind and PRTG measures the network performance statistics and allows Systems and Network administrator to evaluate the arrival bandwidth from the ISP into the gateway and usage of it by the users and measures the traffic record. But it didn't give user session, number of connection created by a single user or record of bandwidth consumption per user [56].

3.3.2.3 Deep log Analyzer

Addis Ababa University also hosts their web server inside the data center and keep a record of access logs. Deep Log Analyzer and WebLog experts were used to extract pertinent traffic statistics from web logs to measure the bandwidth consumptions by global or outside users to the web server access [57].

3.3.2.4 Weblog Expert

Web log expert is log analyzer that extract information related to site's visitors: activity statistics, accessed files, paths through the site, information about referring pages, search engines, browsers, operating systems, and more [58].

3.3.3 Tools Employed

3.3.3.1 Tele Traffic Tapper (ttt)

Tele Traffic Tapper (ttt) is a network monitoring tools [59] which is capable of providing real-time graphical and remote traffic monitoring. ttt displays traffic behavior for the last 60 seconds with the graphs being updated every second by default. In this study, ttt was used to generate reports on a graph about the bandwidth utilization of each user from a given class in a simulated test network environment.

3.3.3.2 GNS3

Our Testbed is based on simulation software, since applying it on a real environment will have an adverse impact on the network performance and might create a service gap during the testing processes [6]. GNS3 is an emulator software that has real world network equivalence.

3.3.3.3 Ubuntu

In order to deploy the bandwidth management prototype software, any software platform could be used. In doing so, the developer has to consider the latency and jitter created by the packets back and forth between the server and switch (router). When a client initiate session to the remote server, the packet had to pass through the switches and gateway device before it forwarded to its destination. If the bandwidth management allocation software is deployed in server and connected to the switch, the traffic path will be totally different. The switches, rather than sending the traffic to its default gateway, it will send it to a server hosting the bandwidth management and the server send it back to the switch to forward it to the gateway then to destination server. This will add extra hop, latencies and jitter for a packet forwarding processes.

In Linux kernel, iproute2 was include that can perform as virtual router or switches. The main objective of using Linux Box as a prototype server is to avoid the packet latency, and since the Linux is equipped with routing capability, all the packets passing via the operating system will be inspected and monitored [60]. The server used to deploy the prototype is configured with two virtual Ethernet interface to monitor one from internal connection destined to the Internet and the other from the Internet destined to a web server hosted inside a data center.

3.4 Current Methods of Bandwidth Management

Currently, the University didn't apply any bandwidth shaping policy. AAU used to apply a proxy server inside the campus and filter out some of the bandwidth greedy application during the working hours [55], but due to availabilities of VPN application the user traffic is not visible on the proxy server since it changes the IP header information which makes it hard to track users browsing history by proxy.

3.5 Proposed Method and System

According to Zant, in developing system there are two ways: Evolutionary and throwaway. In this study, the researcher adopt the evolutionary methods. The dynamicity and complexity [18] of IT service makes the requirements of bandwidth difficult and different as time passes. Evolutionary method initially contains a minimal set of high priority features and then is changed when the new requirements are discovered whereas, in throwaway, methods are developed for a specific, limited purpose and discarded then after [61].

The testbed of the algorithm has with five classes. Root, Student, Staff, Guest and Default classes. The root class belongs to 1:0, the Students class belongs to 1:10, Staffs class belongs to 1:11, Guests class belongs to 1:12 and by default all users which didn't belong to the above class is placed on class of 1:100. Each class is set with different bandwidth rate and individual users from each class will inherit the bandwidth rate assigned to the class. The set used for each class is based the information available at Federal Communication Commission Broadband technical reports [28]. The root class is configured with 5120 kbps, this is the default class that each user's rate shouldn't be above this rate, the student class was configured with 256 kbps minimum rate and 512 kbps ceiling rate, the staff class was configured with 300kbps with ceiling rate of 1Mbit, a Guest class was configured with 128 kbps with no bandwidth

borrowing capability. If a user doesn't have class it will fall into the category of default with 100 Kbit. Below is the subnet assigned for each classes.

Traffic Originated from subnet 10.6.1.0/19 was assigned to student class of 1:10, the packet originated from subnet 10.6.32.0/20 was assigned to staffs class of 1:11, the packet that is originated from a subnet of 10.6.48.0/21 was assigned to Guest class of 1:12. Packets that wasn't originated from those class will be placed on the default class 1:100. Figure 7 below shows the system flow chart of how the bandwidth allocation work.

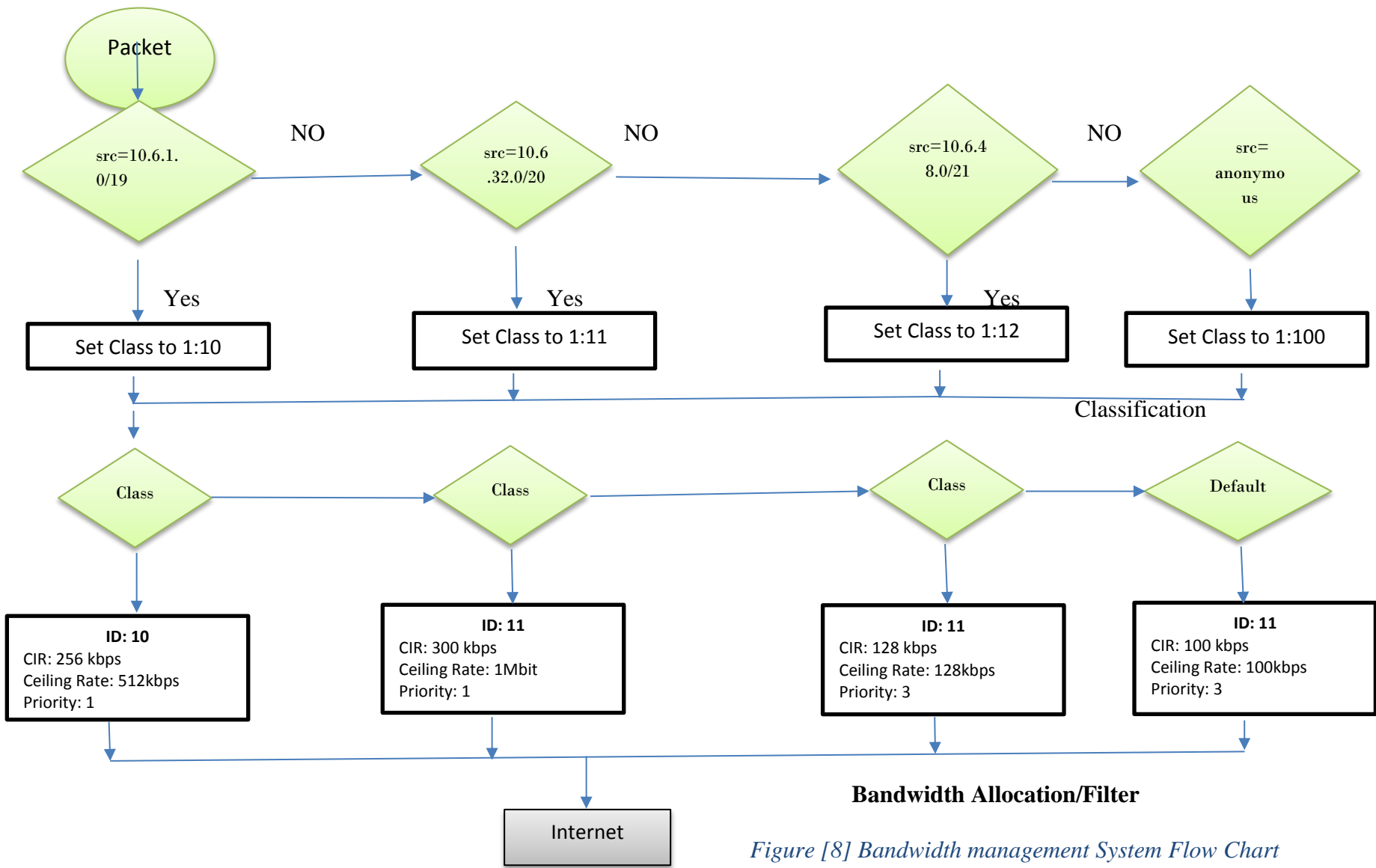


Figure [8] Bandwidth management System Flow Chart

3.6 Tools to be Adapted

3.6.1 Bandwidth Borrowing using Hierarchical Token Bucket (HTB)

Hierarchical Token Bucket (HTB) is a class-based queue discipline. A queue discipline (qdisc) can be seen as a block of box which is able to queue and dequeue packet in order. There are three class types in HTB: *root*, *inner* and *leaf*. Root classes are suited on top of the hierarchy and all traffic goes out through them [62]. A hierarchical token bucket is included on the token bucket theory where token bucket filters are placed in a tree-like structure to form the bandwidth sharing hierarchy. Parent classes are configured with parameters on how bandwidth is to be shared among its child classes. Each class in a Hierarchical token bucket is configured with ***Guaranteed Rate (GR)***, and a ***Ceiling Rate (CR)*** [63].

3.7 Summary

This chapter devoted to explaining methodology, methods, and tools used to collect and analysis network traffics. Different users are assigned to different class to different bandwidth rate with the ability to borrow bandwidth from the parent class if available. Token based dynamic bandwidth allocation algorithm was selected to provide user demanded bandwidths.

CHAPTER FOUR

ANALYSIS AND RESULTS

4.1 Introduction

In today's network, if not controlled, Internet has both negative and positive impact on the production network. The intention of Internet innovation was for the research and transmission of information across the military at first. But in the late 90's it was used by institutions and then used by the general public. Ever since that day, the way of communications, business operation to list a few are connected to the big network called the Internet. Currently, with an Internet of Things (IoT), everything is almost connected to the Internet even the entertainment and streaming media converted from the cable News to the online streaming [64] and bandwidth management become challenging.

In spite of all things are connected to the Internet, it is not the priority of the university to satisfy the entertainment needs of a user at working hours, rather achieving the targeted goals.

There are different applications on the Internet and each application consumes different size of bandwidth. Limits have to be placed for the applications that are non-productive and bandwidth-greedy [65]. To place a limit on bandwidth utilization, a policy has to be developed, and to develop a policy network traffic flow should be monitored constantly and analyzed to determine which applications are the one that consumes most of the bandwidth.

4.2 AAU Network Traffic Analysis

4.2.1 Network Traffic Analysis Using SolarWinds

Bandwidth management is not merely a coping strategy to be employed by those with poor infrastructure and low bandwidth connections; it is essential for an institutional network that has working and good network infrastructure. As the network grows so the complexity of managing it and the cost associated with it. In order to manage network the basic thing to consider is tools, and in many institutions the necessary tools are not yet presented and if they are, they may not be used to the full extent due to the high cost associated with the license and less awareness of IT team on importance of bandwidth monitoring [66].

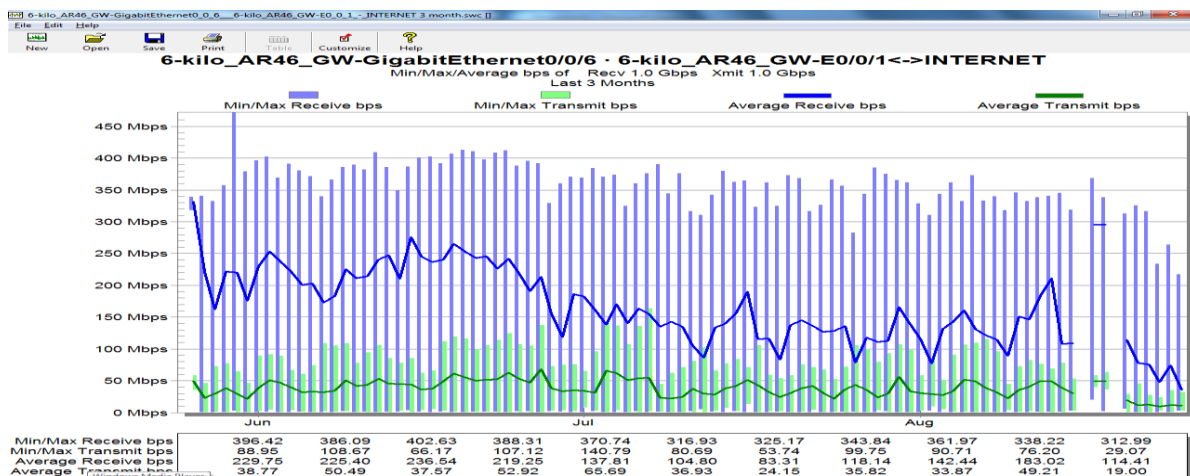


Figure [9] AAU Network Traffic Performances

As show in the above figure, the amount of bandwidth coming to AAU is on the average minimum of <50 mbps and maximum of 300 mbps. This traffic was captured when the subscribed bandwidth rate was 400 mbps. A traffic capture with the bandwidth subscription of 1 gbps was presented in the later section using the PRTG. There were a time when Internet traffic interruption happened during the month of August which might be caused by power interruption or connection failure from the service provider. The data collected show that the Internet traffic performance coming

from ISP is above 300 mbps which accounts for more 75% of the subscribed bandwidth and in order to understand individual bandwidth utilization, a proxy log has been collected and analyzed.

4.2.2 Network Traffic Analysis using PRTG

Monitoring the network performance allows engineers to see if the subscribed bandwidth is being arrived in the campus and utilized to the full extent and allows to decide if additional bandwidth subscription is required. Once the bandwidth measurement is done, a network and system engineer must answer the following question before deciding to increase the bandwidth rate:

- ✓ What type of traffic is most likely consuming all the bandwidth?
- ✓ At what time of the day the consumption reaches its peak?
- ✓ Is there a full distribution of Internet access to all users or used by a few users with a bandwidth-consuming application?

This information allows system administrators and engineers to see the network visibility like top application by traffic, top conversation by traffic, traffic sources by IP addresses [67]. Addis Ababa University didn't deploy network traffic analysis technique [11] on their campuses

A year ago, the connection for AAUNet was 400 Mbps but currently it is 1000 Mbps. Every time when there is performance issues on Internet connection, the university is only considering to add more bandwidth. But according to Aptive [14] and Nahar [66] increasing the bandwidth will not solve the problems. Below is the network performance statistics collected using PRTG before and after the bandwidth was upgraded to 1 Gigabit.

PAESSLER		PRTG Network Monitor	
AAU-Mainrouter-PRTGTraffic-Reprots: (1153) GigabitEthernet0/0/5 Traffic			
Report Time Span:	9/3/2015 12:00:00 AM - 9/4/2015 12:00:00 AM		
Report Hours:	24 / 7		
Sensor Type:	SNMP Traffic 64bit (60 s Interval)		
Probe, Group, Device:	Local probe > Local probe > AAU_Main_Router		
Uptime Stats:	Up:	100 % [23h56m26s]	Down: 0 % [0s]
Request Stats:	Good:	100 % [1263]	Failed: 0 % [0]
Average (Traffic Total):	208,183 kbit/s		
Total (Traffic Total):	2,194,970,318 KByte		

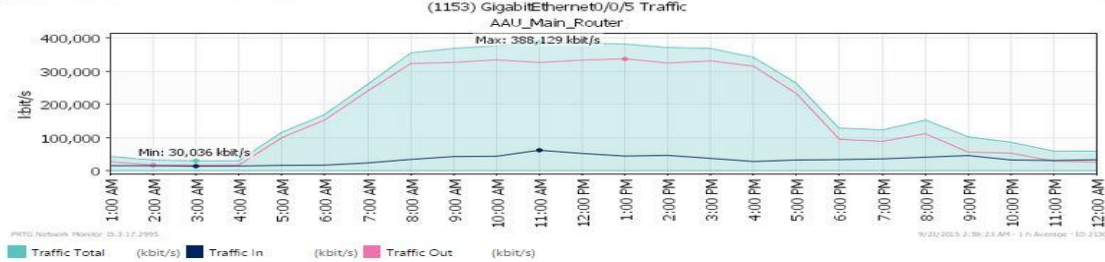


Figure [10] PRTG Daily Graphs at the Edge of AAU

As it is shown in figure 9 above, PRTG was scheduled to record SNMP traffic for every 60 seconds in all day and the record showed between 7:00 PM and 4:00 AM indicated that the network performance was at its lowest point. Around 4:00 AM in the morning, it started to rise and reach to its peak point by 8:00 AM where the academic, and supportive staffs, and students start their socio-economic activities of the day and then after it has a flat line at 379 Mbps rate till 4:00 PM. PRTG was scheduled to collect user’s traffic 24 hours in a day and 7 days in a week for three months from January to March 2017 after the bandwidth was upgraded to 1Gbps. Based on this statistics, like the bandwidth statistics recorded while the bandwidth was 400Mbps by SolarWinds, the performance of the network was at its peaks which is an indication of increasing the bandwidth is not a solution for wise utilization of bandwidth.

Table [1] PRTG Total and Average Traffic Monitor for both In and Out.

Channel	Average	Total
Traffic Total	208,183 kbit/s	2,194,970,318 KByte
Traffic In	32,502 kbit/s	342,686,596 KByte
Traffic Out	175,681 kbit/s	1,852,283,721 KByte

Date Time	Traffic Total (volume)	Traffic Total (speed)	Traffic In (volume)	Traffic In (speed)	Traffic Out (volume)	Traffic Out (speed)	Coverage
Sums (of 24 values)	2,194,970,318 KByte		342,686,596 KByte		1,852,283,721 KByte		
Averages (of 24 values)	91,457,097 KByte	208,183 kbit/s	14,278,608 KByte	32,502 kbit/s	77,178,488 KByte	175,681 kbit/s	100 %

Within 24 hours a total of 2,194,970,318 kilobits of data was recorded which is around 2093 Gigabit, 84.6% of the traffic was recorded as outbound traffic and 15.4% of the traffic was used for inbound traffic. Since it will not be viable to conclude the university network performance based on a single day data below is a week of 3-9-2015 to 10-9-2015 and three months of January to March 2017 data that used to analysis the university network traffic.

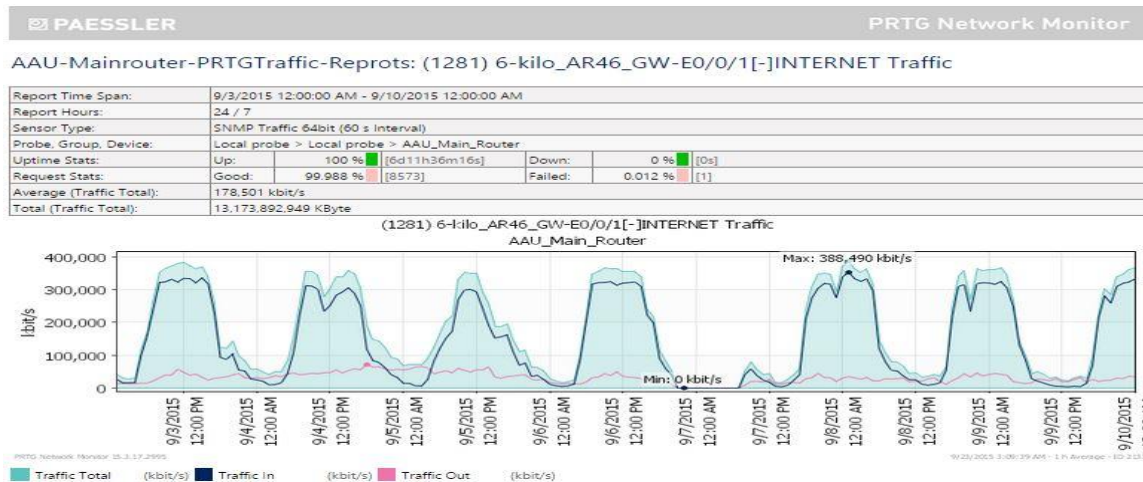


Figure [11] PRTG Weekly Graphs at the Edge of AAU

In the weekly traffic record the subscribed bandwidth was 400Mbps, and most of the time the traffic is above 300 Mbps. During the week, the maximum traffic was recorded at 9/08/2015 which is around 380 Mbps. In the rest of the week, the average traffic record was 178,501 kbps. Based on the traffic pattern recorded in daily or weekly, the network traffic statistics shows that there was high bandwidth utilization and good network performance.

From the above figure the following facts can be drawn:

- ✓ The highest traffic was recorded on 9/8/2015 with 388,490 kbps (388.49 Mbps)
- ✓ Except for the second day of the week, there was more than 300 Mbps on average on each day.
- ✓ 87.23% of the traffic was an outgoing traffic.
- ✓ 99.98% of the requested traffic was successful.
- ✓ On 9/7/2015 no traffic was recorded by PRTG, due to connection problem or power issue.

Figure 11 below shows a three months of PRTG reports after bandwidth is upgraded to 1Gbps:

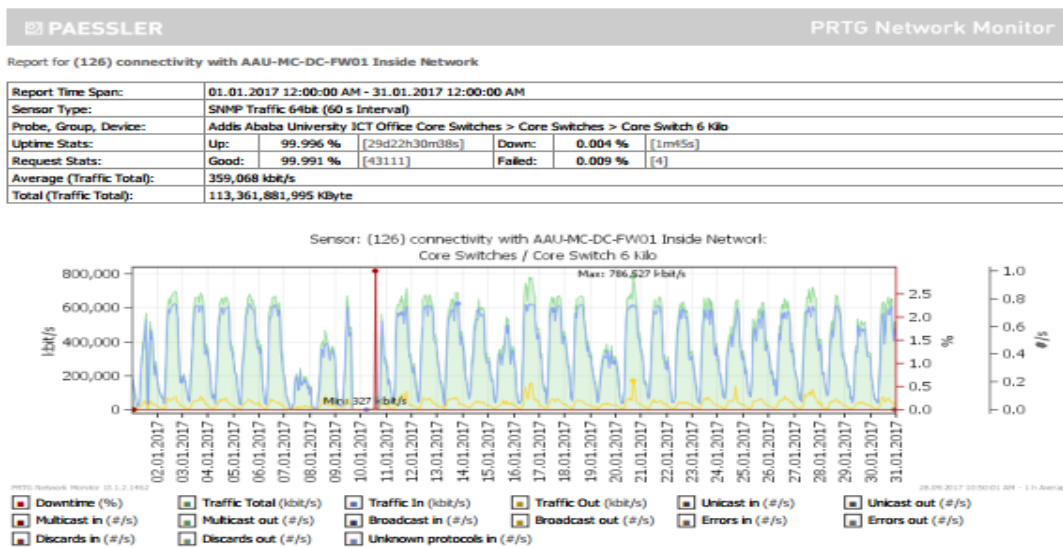


Figure [12] AAU PRTG Record of January

Based on the record statistics, AAU Internet Usage is increasing even if the university added additional bandwidth. Only on 08-01-2017, the smallest bandwidth traffic was recorded, which was less than 200 Mbps. In the rest of the months, the speed and utilization were above 400 Mbps on average with the maximum record was recorded on March 23, 2017, which is 819,263 kbps.

PAESSLER		PRTG Network Monitor	
Report for (126) connectivity with AAU-MC-DC-FW01 Inside Network			
Report Time Span:	01.02.2017 12:00:00 AM - 28.02.2017 12:00:00 AM		
Sensor Type:	SNMP Traffic 64bit (60 s Interval)		
Probe, Group, Device:	Addis Ababa University ICT Office Core Switches > Core Switches > Core Switch 6 Kilo		
Uptime Stats:	Up: 99.998 % [26d21h31m29s]	Down: 0.002 % [45s]	
Request Stats:	Good: 99.951 % [38715]	Failed: 0.049 % [19]	
Average (Traffic Total):	412,857 kbit/s		
Total (Traffic Total):	117,047,679,366 KByte		

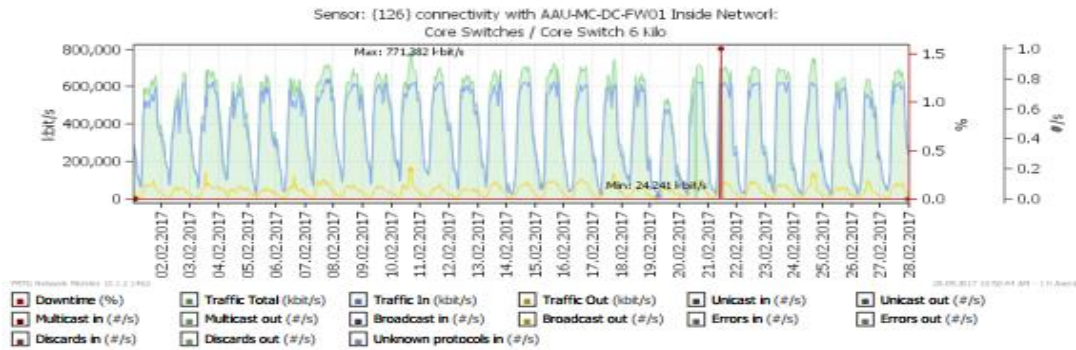


Figure [13] AAU PRTG Record of February

On the month of February 2017, the traffic record shows the bandwidth utilization was also high. Was it for production purpose only? To determine that it requires packet flow analysis and Network security audit, which is not the scope of this thesis.

The average usage in the month was 412,857 kbps with the smallest rate being recorded on 20th of February 2017, which was 24,241 Kbps.

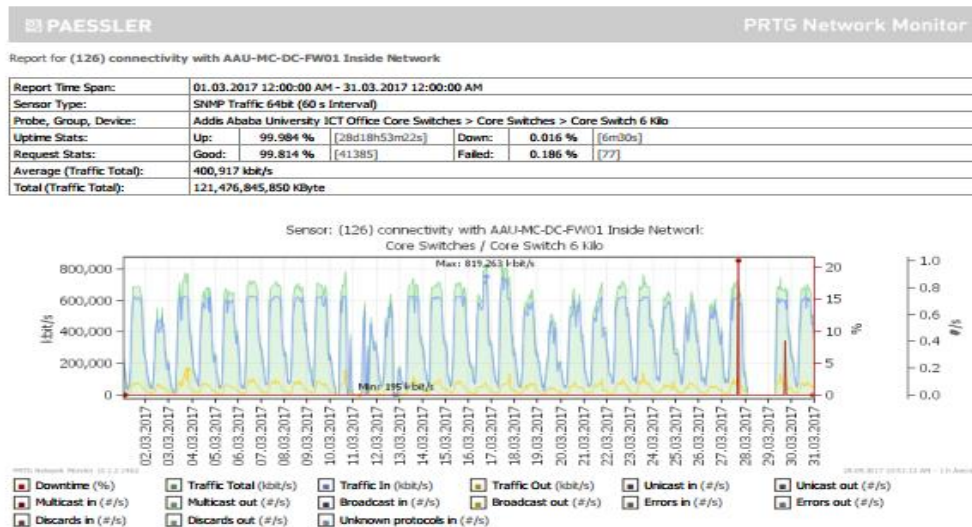


Figure [14] AAU PRTG Record of March

The same network performance was recorded during the month of March. These records show us the university uses the subscribed bandwidth to the maximum.

4.2.3 Analysis of Proxy Logs

Using SAWMILL software proxy log files were analyzed, and the following information were extracted:

Hits, page views, visitors, size of bandwidth, sessions durations, source IP address along with the number of hits, the amount of bandwidth being generated using that source IP address, pages/directories that was accessed, destination IP accessed by end users, URLs which will shows the pattern of the users and the amount of bandwidth being accessed from that domains.

Eight days of proxy logs from three different proxy server and eight days of web access logs were analyzed using SAWMILL, Deep log Analyzer and WebLog Expert. The proxy logs were captured from College of Natural and computational science, Addis Ababa Institute of Technology and Addis Ababa University main campus and all sub-campuses within the main campus.

4.2.4 Proxy Log Analysis: General Statistics

The following information was extracted from proxy server's log and might be ambiguous since it contains information about hits, page views, bandwidth consumed, sessions, source address, domains accessed and all the details that web server should have. This is because proxy server is a gateway between the local network and the remote network where user access resources through those proxy servers and it simulates the web server using a caching system [68] that caches everything accessed from your local network and recorded it as logs. Therefore, the information

presented below is not from the web server out on the Internet, rather from the proxy server deployed inside AAUNet.

There are lots of information that could be extracted from the proxy logs, but information that are pertinent to this thesis is extracted:

Hits: Hits are accepted log entries. A proxy log recorded every hit requested by each user, this can be anything on the websites, like pages, animation, audio, text... etc and if there are no log filters and none of the logs have corrupt dates, and then the log entries accepted by the log filters will count towards the hits total. When the users hit a page, it will load all the contents that used to display that specific request, so accessing one file might generate more than one hits [69]. There was 66,520,191 total hits within 8 days with 8,315,023 hits on average per day from 13th of April 2016 to 20th of April 2016.

Page Views: Page views corresponds to hits on pages. A hit on index HTML might be followed by 100 hits on 100 images, style sheets, JavaScript in the background that appears in the index page, but the analyzer count it as a single page view. There was a total Page views of 57,616,722 and average page views of 7,202,096 from 13th of April 2016 to 20th of April 2016.

Visitor: Visitors corresponds roughly to the total number of people who visited the site. If a single person visits the site and looks at X number of pages, that will be count as X page views, but only one visitor. SAWMILL defines visitors to be "unique hosts" --- a hit is assumed to come from a different visitors if it comes from different hostname or IP address. In the statistics generated, there were a total of 12,295 visitors and an average of 1536 visitors from 13th of April 2016 to 20th of April 2016.

Bandwidth: Each and every hits and page accessed requires a certain amount of bandwidth. Every time a user or script accessed certain pages or applications, the bandwidth consumption is recorded and tracked for every log entry and is accepted "as a hit" or "as a page view". Based on the log entries analysis there was a total of 6.19 TB of bandwidth usage within 8 days with an average of 792.68 GBs consumption per day in the month of April, 2016.

Table [2] AAU Access Logs Overview

Addis Ababa University 8 days Proxy logs Analysis
Single-page Summary 13/Apr/2016 – 20/Apr/2016, 8 days (entire date range)

Overview ⚙️

		Avg/day
Hits	66,520,191	8315023.9
Page views	57,616,772	7202096.5
Visitors	12,295	1536.9
Size	6.19 TB	792.68 G
Sessions	70,689	8836.1
Session duration	9y 114d 09:09:07	1y 59d 22:08:38

Here are a summary of above analysis: over 66.5 million of hits was recorded on 57.62 million of pages view, a total of 12,259 users consumes more than 6.19 TB of data from 13th of April 2016 to 20th of April 2016.

Below is list of the top 10 bandwidth consumers, types of files accessed, the hours of the day with the highest traffic and the highest hits recorded.

Top 10 bandwidth Consumer based on source IP address

Table [3] AAU Access Logs Details

Source IPs								
Source IP	Hits			Page views	Visitors	↓ Size	Sessions	Session duration
1 10.5.42.142	12,727	0.0 %		10,450	1	42.92 G	7	10:50:16
2 10.5.14.252	330,485	0.5 %		312,119	1	39.95 G	21	1d 07:20:11
3 10.5.56.178	34,014	0.1 %		33,543	1	37.37 G	11	20:49:44
4 10.5.42.97	31,054	0.0 %		26,032	1	33.72 G	2	07:32:04
5 10.4.91.254	302,619	0.5 %		262,385	1	31.20 G	6	1d 22:24:36
6 10.5.45.169	49,362	0.1 %		48,325	1	30.77 G	9	2d 00:26:50
7 10.9.42.198	81,894	0.1 %		72,556	1	30.20 G	16	20:32:57
8 10.6.18.240	262,403	0.4 %		207,877	1	29.49 G	15	3d 15:16:35
9 10.6.64.97	49,626	0.1 %		46,925	1	28.39 G	13	21:08:30
10 10.5.23.194	655,675	1.0 %		654,763	1	28.02 G	4	09:01:51
12285 other items	64,710,332	97.3 %		55,941,797	-	5.87 TB	-	9y 101d 17:45:33
Total	66,520,191	100.0 %		57,616,772	-	6.19 TB	-	9y 114d 09:09:07

From the above record, the SAWMILL log analyzer software listed out the top 10 users of bandwidth and the associated pages viewed, it is also very good for the algorithm development to know session duration of a single user since the idle time calculation will be vital in maintaining the spare bandwidth.

As it is shown from the table 3 of the top ten users, most of them used more than 28 GB within a day and an average of 9 hours session was recorded.

A machine with the IP address of 10.5.42.142 used 42.9 GB of bandwidth with 10,452 pages viewed and had around 11 hours of sessions. There were 12,295 unique users, and from those users, 3.7% of the bandwidth was used only by 10 of them, which indicates the requirement of bandwidth management for a fair share of bandwidth.

Hours of daily data record:

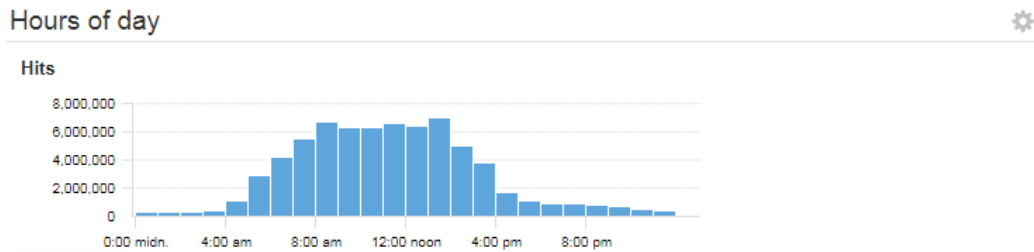


Figure [15] Hours of the Day Hits Record

As it is shown both at figure 14 and table 4, same to the PRTG traffic record, the SAWMILL log analyzer also shows the utilization of bandwidth started to raise at 4:00 AM early morning and start to decline 4:00 PM, which depends on the socio-economic activity of the university communities. Every resource accessed on the Internet requires the utilization of a certain amount of bandwidth and as the number of visitors increases so does the bandwidth utilization [12]and network congestions.

Table [4] General Statistic of User Traffic within Hours of Day

↑ Hour of day	Hits	Page views	Visitors	Size	Sessions	Session duration
1 midnight - 1:00 AM	167,564	144,785	428	44.04 G	468	11d 23:22:36
2 1:00 AM - 2:00 AM	133,050	118,662	358	26.19 G	398	10d 07:28:15
3 2:00 AM - 3:00 AM	151,211	130,028	340	27.15 G	369	9d 07:56:40
4 3:00 AM - 4:00 AM	273,451	243,508	798	53.09 G	1,002	15d 07:45:10
5 4:00 AM - 5:00 AM	906,587	784,691	1,866	177.55 G	2,659	42d 09:04:34
6 5:00 AM - 6:00 AM	2,727,511	2,334,922	4,776	368.81 G	8,382	143d 06:26:54
7 6:00 AM - 7:00 AM	4,098,623	3,486,127	5,961	416.80 G	11,889	252d 20:17:57
8 7:00 AM - 8:00 AM	5,307,843	4,569,776	6,461	475.23 G	13,168	306d 13:26:09
9 8:00 AM - 9:00 AM	6,545,627	5,769,013	6,627	497.16 G	13,783	334d 10:16:53
10 9:00 AM - 10:00 AM	6,149,579	5,411,472	6,295	512.17 G	13,004	286d 01:46:11
11 10:00 AM - 11:00 AM	6,140,471	5,368,268	6,544	527.10 G	13,497	306d 16:27:34
12 11:00 AM - noon	6,454,678	5,684,000	6,624	464.99 G	13,767	337d 08:50:29
13 noon - 1:00 PM	6,258,851	5,442,214	6,616	464.64 G	13,743	335d 13:54:58
14 1:00 PM - 2:00 PM	6,855,450	6,028,151	6,489	516.46 G	13,121	312d 11:41:23
15 2:00 PM - 3:00 PM	4,851,462	4,176,786	5,774	453.32 G	11,033	219d 00:40:40
16 3:00 PM - 4:00 PM	3,677,277	3,069,047	4,335	419.11 G	7,395	156d 07:48:17
17 4:00 PM - 5:00 PM	1,561,262	1,318,416	3,031	240.31 G	4,184	85d 13:49:54
18 5:00 PM - 6:00 PM	977,429	834,994	2,195	138.84 G	2,921	61d 22:07:06
19 6:00 PM - 7:00 PM	734,491	610,575	1,699	102.83 G	2,095	45d 13:46:20
20 7:00 PM - 8:00 PM	770,445	640,420	1,553	102.44 G	1,834	40d 21:49:09
21 8:00 PM - 9:00 PM	639,517	516,544	1,213	97.76 G	1,386	29d 11:47:59
22 9:00 PM - 10:00 PM	502,666	407,453	863	86.98 G	944	23d 17:49:06
23 10:00 PM - 11:00 PM	366,999	306,220	665	70.44 G	737	18d 04:43:19
24 11:00 PM - midnight	268,147	220,700	502	58.04 G	548	14d 00:01:34
Total	66,520,191	57,616,772	-	6.19 TB	-	9y 114d 09:09:07

Table [5] SAMWILL File Type Activities.

File type	↓ Hits		Page views	Visitors	Size	Sessions	Session duration
1 (no type)	37,712,345	56.7 %	37,712,345	12,108	4.14 TB	64,071	6y 356d 22:16:04
2 MP4	6,710,016	10.1 %	6,710,016	2,608	674.59 G	3,855	24d 12:19:10
3 JPG	2,984,788	4.5 %	0	8,419	63.71 G	0	00:00:00
4 JS	2,239,538	3.4 %	0	8,321	33.64 G	0	00:00:00
5 MKV	1,499,604	2.3 %	1,499,604	259	321.73 G	323	7d 14:27:07
6 PNG	1,489,290	2.2 %	0	8,403	21.27 G	0	00:00:00
7 PHP	1,331,968	2.0 %	1,331,968	8,691	33.64 G	24,919	52d 01:26:40
8 GIF	1,212,596	1.8 %	0	8,256	7.31 G	0	00:00:00
9 XML	1,063,718	1.6 %	1,063,718	6,545	3.95 G	21,596	110d 15:05:47
10 PDF	996,494	1.5 %	996,494	3,670	124.49 G	7,573	31d 23:19:03
9899 other items	9,279,834	14.0 %	8,302,627	-	814.04 G	-	1y 260d 16:15:16
Total	66,520,191	100.0 %	57,616,772	-	6.19 TB	-	9y 114d 09:09:07

Most of the applications or files that are being accessed on the web have types, it could be a document in a different format, audio, video or some sort of applications. Table 3 shows 57.6% of the files accessed by users don't have any type, it could be a P2P share which requires a packet flow analysis, and 10.1% of the hits is MP4, which is a video format. It's not the objective of this thesis to investigate flow analysis and security audit but it is in best interest of the university to conduct a network flow analysis and network security audit check to investigate if there is a network loop or some sort of script run in the network.

Table [6] Mime Files Accessed Record

Mime type	↓ Hits		Page views	Visitors	Size	Sessions	Session duration
1 -	27,077,954	40.7 %	26,342,472	12,042	3.67 TB	62,820	5y 305d 19:13:49
2 text/html	19,891,063	29.9 %	19,567,818	11,624	54.28 G	55,665	1y 218d 13:27:55
3 image/jpeg	3,229,692	4.9 %	407,611	8,616	69.17 G	9,697	6d 07:03:34
4 image/gif	2,568,641	3.9 %	1,600,048	8,164	8.24 G	19,888	33d 15:25:39
5 application/octet-stream	2,090,945	3.1 %	2,084,980	9,203	873.48 G	31,052	260d 17:48:22
6 image/png	1,516,226	2.3 %	214,202	8,368	23.43 G	10,822	2d 19:01:41
7 application/javascript	1,359,807	2.0 %	522,470	7,328	15.67 G	14,596	8d 07:10:00
8 text/javascript	1,101,400	1.7 %	554,486	7,794	15.42 G	16,659	11d 09:57:52
9 application/ocsp-response	972,273	1.5 %	972,273	8,584	1.16 G	31,483	50d 21:31:17
10 application/x-javascript	861,906	1.3 %	303,554	7,399	9.02 G	10,072	4d 12:36:29
510 other items	5,850,284	8.8 %	5,046,858	-	1.48 TB	-	306d 09:52:29
Total	66,520,191	100.0 %	57,616,772	-	6.19 TB	-	9y 114d 09:09:07

Page is any file or content delivered by a web server that would generally be considered as a web document. That documents or contents will be delivered to clients using HTML, XML, and the content could be an image with a different format, documents in the form of a word, pdf, scripts or application, as it is shown in figure 19 40.7% of the access has no type and has the longest sessions. Only 29.9% of the type accessed was document/pages.

4.2.5 Analysis of Web Logs using WebLog Expert

Weblog expert gives you an information about site's visitors: activity statistics, accessed files, and paths through the site, information about referring pages, search engines browsers, operating systems and more from Web Access Logs [58].

The weblog expert log analyzer generates reports of the <https://aau.edu.et> web site access statistics on a daily basis as shown below in table 7. The highest hits were recorded on the 2nd day of the week November 28, 2016, which is 197,030 hits and the second one is registered on November 29, 2016, with 172,310 hits, whereas the lowest hits recorded on December 4th of 2016 with 21,251 hits. Regarding the Page views, the highest hits to AAUNet web server is recorded on November 31, 2016, and the lowest is on December 4th, 2016. A unique IP address is a way how WebLog Expert determines how many visitors are accessing the web servers, and based on the WebLog experts statistics the highest visitor is recorded on December 3, 2016, and the least visitor is registered on December 4th, 2016. When a user accesses the web from outside, the web server uses the internal bandwidth to process their request and retrieve the necessary information since it didn't have a dedicated bandwidth for it. Unlike the internal users the bandwidth usage from outside to web server hosted inside the university is smaller comparatively. The highest bandwidth

usage in the week is registered on November 28th, 2016, with 6,081,891 kb (5939.3 MB) and the smallest bandwidth usage is registered on December 4th, 2016.

Table [7] Web Activities Statistics by Day of a Week for AAUNet Web server

Daily Activity					
Date	Hits	Page Views	Visitors	Average Visit Length	Bandwidth (KB)
Sun 11/27/2016	81,950	29,106	2,905	09:22	1,760,563
Mon 11/28/2016	197,030	49,124	5,219	05:29	6,081,891
Tue 11/29/2016	172,310	29,710	5,341	05:54	4,789,479
Wed 11/30/2016	161,944	27,229	5,385	07:24	5,479,685
Thu 12/1/2016	156,674	31,200	5,430	05:41	4,157,133
Fri 12/2/2016	145,209	24,859	5,466	04:07	4,112,498
Sat 12/3/2016	115,866	16,188	5,005	03:44	3,668,519
Sun 12/4/2016	21,251	2,205	921	05:26	604,521
Total	1,052,234	209,621	35,672	05:43	30,654,294

The average bandwidth utilization of the university web server was 3,831,785 KB within eight days. Based on table 7 data, there is no direct relation between page views and visitors or visitor and bandwidth utilization. On the day of 11/28/2016 there were 5,216 visitors and usage of 6,081,891 KB of Bandwidth, and on 11/29/2016 there were 5,341 visitors but the bandwidth utilization was 4,157,133 KB which is less than the bandwidth used at 11/28/2016, even on 2/12/2016 the number of visitors were 5,466 which is higher than the visitors recorded on 28 and 29 of November 2016, but the bandwidth utilization is lesser, which was 4,112,498 KB.

Activity by Hours of Day:

As it is shown in figure 15 below, the highest visitor of the website is registered between 4:00 AM to 8:00 AM in the morning, and the least consumptions were recorded after lunchtime tile 8:00 PM in the evening. As it is shown figure 15 below, the network traffic statics is directly related to the socio-economic activities of the university community that the traffic is high during the regular working hours of the university.

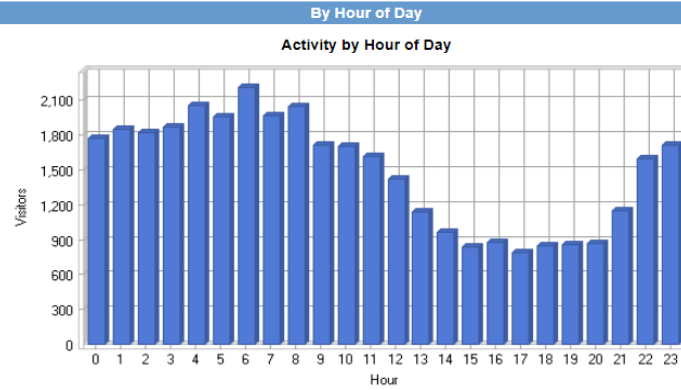


Figure [16] Visitors activities by Hours of Day

Table 8 shows the figurative statistics of the daily activities of the university's website. The highest hits and page views were recorded between 23:00 to 23:59(11:00 to 11:59 PM) which is 89,078 hits and 31,693 page views , whereas the lowest hits and page views are recorded between 19:00 to 19:59(7:00-7:59 PM) which has record of 10,224 hits and 2,309 page views respectively. Highest visitors was recorded on 6:00 – 6:59 with 2,214 visitors, the smallest visitors record was at 17:00-17:59 which was 793. As per the Bandwidth utilization of the day, the maximum bandwidth usage was recorded at 04:00-04:59 which was 3,493,673 KB while the least bandwidth utilization is recorded at 19:00-19:59 that has a record of 241,801 KB.

Table [8] Activity by Hour of Day

Activity by Hour of Day				
Hour	Hits	Page Views	Visitors	Bandwidth (KB)
00:00 - 00:59	73,643	12,177	1,769	2,088,055
01:00 - 01:59	80,280	13,748	1,852	2,143,535
02:00 - 02:59	60,490	10,584	1,824	1,588,996
03:00 - 03:59	63,239	11,283	1,870	1,829,809
04:00 - 04:59	80,626	11,459	2,055	3,492,675
05:00 - 05:59	75,935	13,645	1,961	2,214,893
06:00 - 06:59	80,820	14,427	2,214	2,408,256
07:00 - 07:59	58,341	7,548	1,971	1,508,065
08:00 - 08:59	56,099	11,279	2,044	1,541,128
09:00 - 09:59	44,547	6,196	1,718	1,585,189
10:00 - 10:59	36,042	4,995	1,705	913,669
11:00 - 11:59	31,337	4,674	1,613	854,066
12:00 - 12:59	26,774	4,403	1,425	687,246
13:00 - 13:59	21,314	3,697	1,137	651,365
14:00 - 14:59	19,238	4,150	961	1,351,055
15:00 - 15:59	14,226	3,793	841	327,127
16:00 - 16:59	15,430	4,212	876	301,944
17:00 - 17:59	13,894	4,283	793	267,340
18:00 - 18:59	12,426	4,272	845	259,423
19:00 - 19:59	10,224	2,309	861	241,801
20:00 - 20:59	12,333	2,419	871	312,261
21:00 - 21:59	22,325	5,159	1,148	494,432
22:00 - 22:59	53,573	17,216	1,599	1,795,705
23:00 - 23:59	89,078	31,693	1,719	1,796,244
Total	1,052,234	209,621	35,672	30,654,294

Daily file type access:

File type access gives an insight for the administrator what sort of files are being accessed frequently and how much bandwidth was utilized so they can find a way to provide the necessary information to the public without consuming most of the bandwidth. The highest file type accessed from Addis Ababa university website is CSS (Cascading Style Sheet) and JS (JavaScript). The reason why CSS and JS are the highest one is that accessing a single page triggered those script to run on background [69].

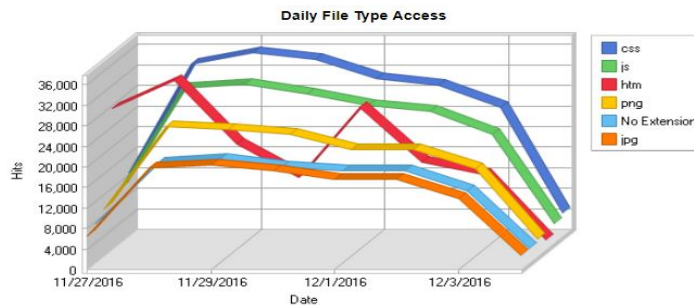


Figure [17] Daily File Type Access

Most Downloaded Files:

Most users who access the university main website downloaded a PDF (Portable Document Format) file as shown in figure 17 below. Since pdf and documents are not the much bandwidth consuming application and as it is shown in figure 20 below, most of the bandwidth is consumed by online streaming and peer to peer files sharing.

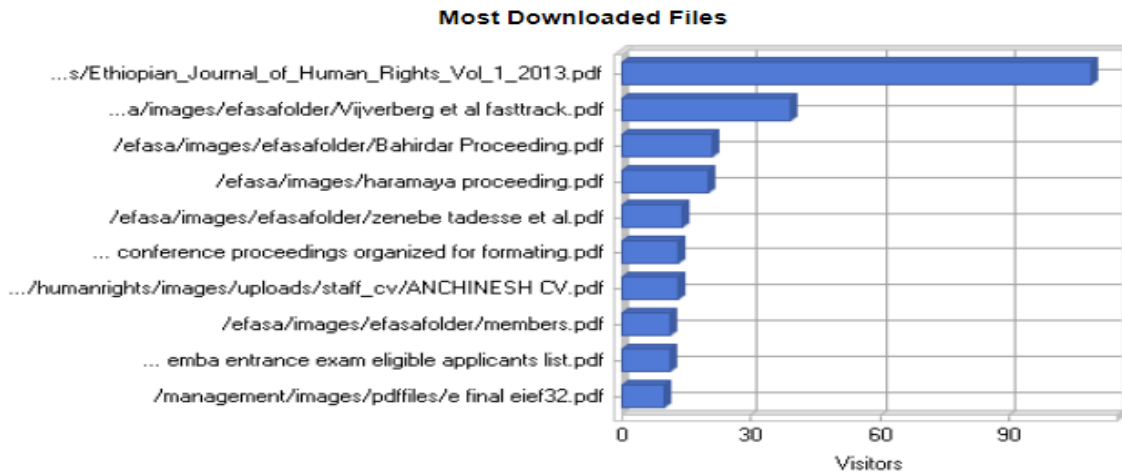


Figure [18] Most Downloaded Files

4.2.6 Application traffic reports

From proxy log and Web Log analysis, the total number of hits, pages viewed, visitor and bandwidth usage, and the amount of bandwidth consumed by an individual user, at what time of the day most of the hits were registered which allows in investigating user traffic patterns, high traffic during a working hour and unbalanced bandwidth sharing across within the user are presented.

Below figure 18 shows which applications exhaust bandwidth. Using the packet captured on Next Generation Firewall (NGFW) device located in the main campus network it is shown that the most

bandwidth utilizing application is YouTube which consumes 1529 GB in a single day whereas the HTTP streaming took the second places with 403 GB.

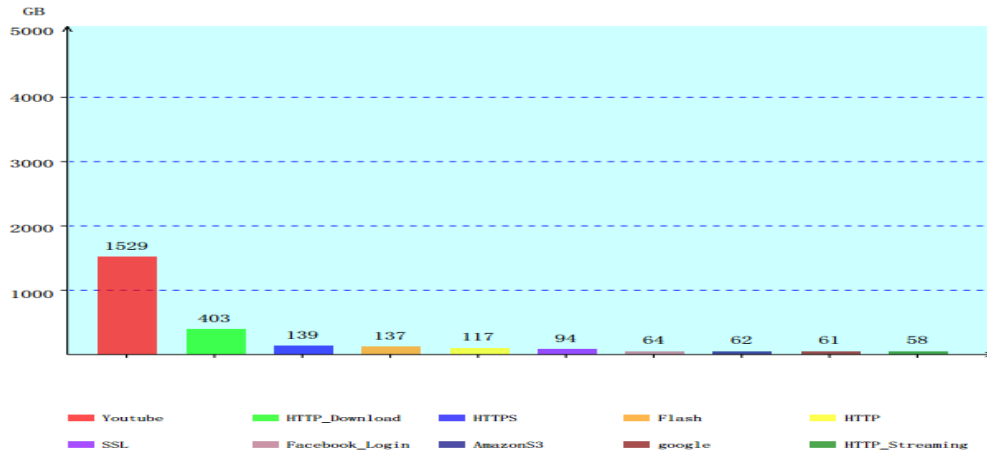


Figure [19] Application Traffic Report at AAU Main campus Firewall

4.3 Summary

This chapter devoted to analyzing network traffics using offline and live captured data. It has also evaluated the bandwidth consumptions of each user, at what time more traffic was generated, and the bandwidth consumption from a global user. Based on the statistics on bandwidth utilization extracted from proxy logs, there was unbalanced bandwidth utilization between users in the university that a few user consumes more bandwidth with bandwidth greedy application and other users struggle to access basic internet services like email access.

CHAPTER FIVE

Designing Bandwidth Allocation Algorithm

5.1 Bandwidth Control Concept

This work rests on the concept of providing an assured minimum amount of bandwidth rate to each user. Currently, AAUNet has 1 Gbps incoming connection from ISP [36]. This bandwidth is used by university community for internal and global use of AAU network.

In normal mode, total bandwidth utilization of a user may not exceeded than the assigned rate. Using those bandwidth intensive application requires a huge amount of bandwidth and user may require to exceed the assigned bandwidth rate. A group of user is configured with guaranteed rate and/or ceiling rate that they can extend the bandwidth utilization, provided there is a free bandwidth in the bucket. This allows for flexibility of network connections within the groups to use the required bandwidth.

Each group (IP subnet) has Minimum Rate (MR), Actual Rate (AR), and Configured (ceiling) Rate (CR). The dynamic bandwidth controller will always monitor and analyze the traffic of each user in the group and calculate the bandwidth size every time when the packet is passing through network from that specific user and compare it with the allocated rate given to the group. Once the controller determines that a user in a group didn't utilize their actual bandwidth in a given time frame, it will shrink the unused bandwidth of that user and collect it back to the bucket allowing a user configured with Ceiling Rate to borrow bandwidth from the bucket.

In designing bandwidth allocation algorithm, there is one question that needs to be answered:

What if the allocated bandwidth rate for each user is more than a total bandwidth subscribed rate from ISP and can't provide a minimum rate for an incoming user?

The assumption on developing Dynamic Bandwidth allocation algorithm is to take advantage of server attribute of a shared network [26]:

- All user are typically not connected to the network at a time.
- Even when connected, a user is not transmitting a packet at all time.
- And most traffic occurs in bursts, that there are a packet request gaps.

5.2 Proposed Bandwidth Allocator

This dynamic bandwidth allocator works by classifying users into groups and the allocation of bandwidth rate depends on a group where a user belongs to. The classification is based on the user the university; the university has four kind of users, student, staff, guest and higher management staf. In practice and based on industry standard grouping user contributes for the performance of the network [70] with different level of access, so user must be grouped based on a certain characteristics and each group should be granted network resource with restricted access and each user in the organization will not have equal access to every resources, same is to bandwidth allocation. Each group assigned with Guaranteed Rate, where every user in the group is granted to use, Ceiling Rate, an allocated rate or configured rate if a user wishes to grow beyond the GR. This allows the system administrator to allocate a minimum amount of bandwidth [28] that are granted to use when connected to the network and the maximum amount of bandwidth that a single user can extend. User will not extend beyond the maximum amount of bandwidth allocated for that group.

5.3 Bandwidth Allocation Prototype Design

The prototype for this thesis was designed by classifying users into group or class. Each user in the class inherits the characteristics and bandwidth allocation of a class. For each class a guaranteed bandwidth has been allocated and based on the priority set for each class, ceiling rate also configured giving user within the class to expand bandwidth usage beyond the actual rate if there is bandwidth in the bucket. A class of Student and Staff is configured to borrow bandwidth from the pool if available where as guest and default user groups will only uses the allocated bandwidth.

Figure 19 below is the model used to allocate bandwidth for each user in the class.

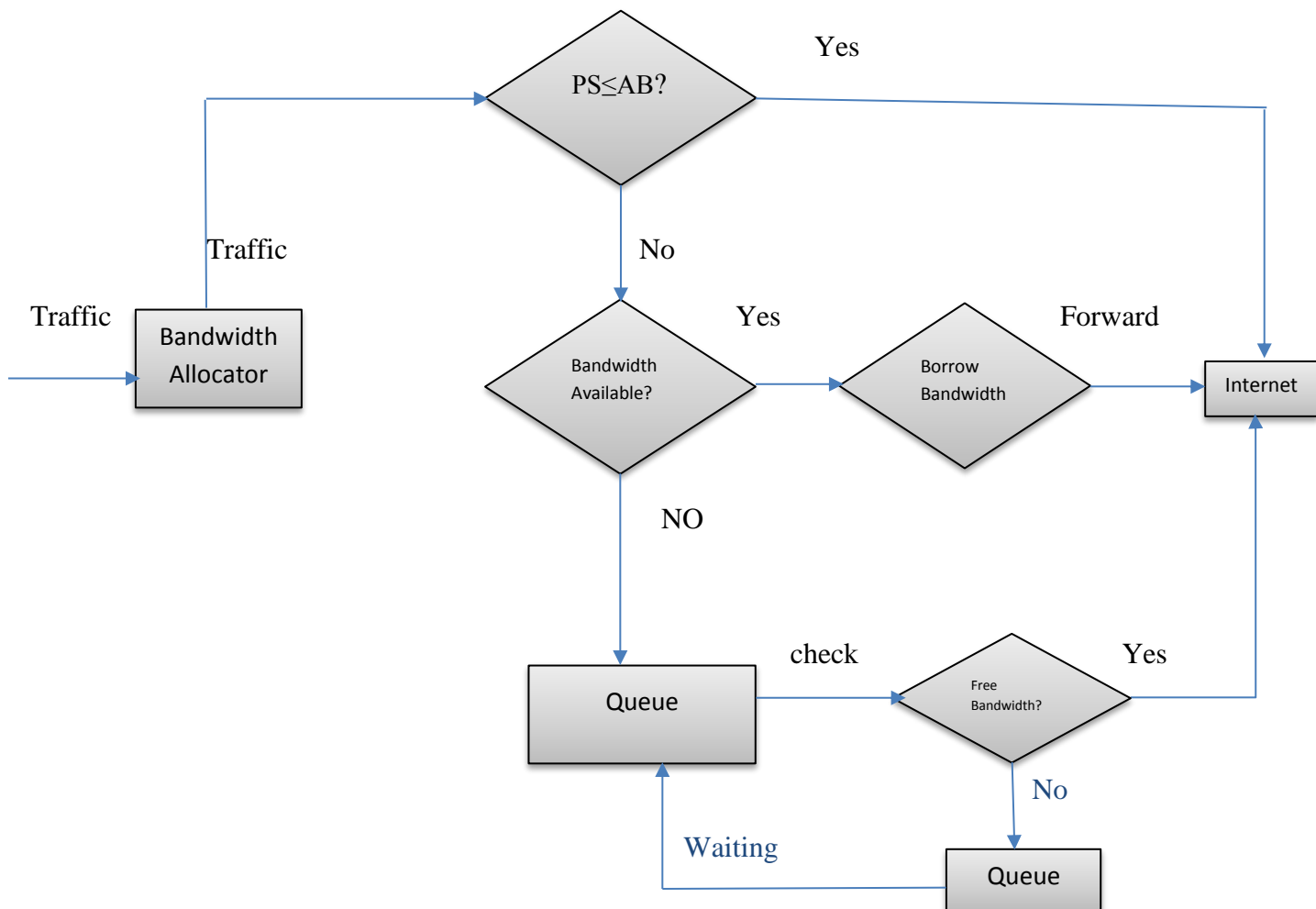


Figure [20] Prototype Design

NB: Whereas PS is Packet Size, AB is Allocated Bandwidth.

If the packet size of the a user traffic is less than the allocated bandwidth the algorithm forwards the packet to the link, otherwise if the packet size of the traffic is above allocated bandwidth, the algorithm will check if the user is allowed to extend (borrow) bandwidth utilization above its actual rate then it will extend its bandwidth utilization to the configured (ceiling) rate, else it will be queued till free bandwidth is available in the bucket. No packet will be dropped.

5.4 How Dynamic Bandwidth Allocator Works

The dynamic bandwidth allocator enables network administrators to manage the bandwidth usage by groups by subnet:

- It allows network administrator to place an individual limit on bandwidth utilization.
- Traffic can be prioritized. For example, traffic that is originated from staff or student could have a high priority at the time of congestion than traffic that is originated from guest or default and those prioritized class of user can be configured to borrow bandwidth.

Therefore, by balancing the bandwidth assigned within the class to a different protocols network performance in the campus and specifically within the group can be optimized.

5.5 Bandwidth Allocation Policy

For this thesis work, the minimum bandwidth requirement defined by Federal Communication Commission Broadband [28] was used to grant a user with a minimum and maximum amount of bandwidth. When user connects to AAUNet, he/she will get a minimum amount of bandwidth rates that allows them for basic Internet access like reading and downloading emails, surfing on web without accessing online streaming or downloading huge files. The algorithm monitors user bandwidth request continuously and if the user request is above the minimum rate assigned, the algorithm allows to extend beyond the minimum rate if the user is configured to do so.

5.6 Dynamic Bandwidth Allocator Prototype Component

The following major components are included in the bandwidth allocator prototype:

- GNS3, applying the prototype test in the real environment will have an adverse impact on the network services and could create service gap, so GNS3 emulation software was used to test the prototype. And inside the GNS3, the following component was included:
 - a. Ubuntu 14.04
 - b. Monitoring tools, BandwidthD, and ttt were installed inside Ubuntu 14.04.
 - c. Windows 7 was installed and integrated with GNS3 emulation software for client access.

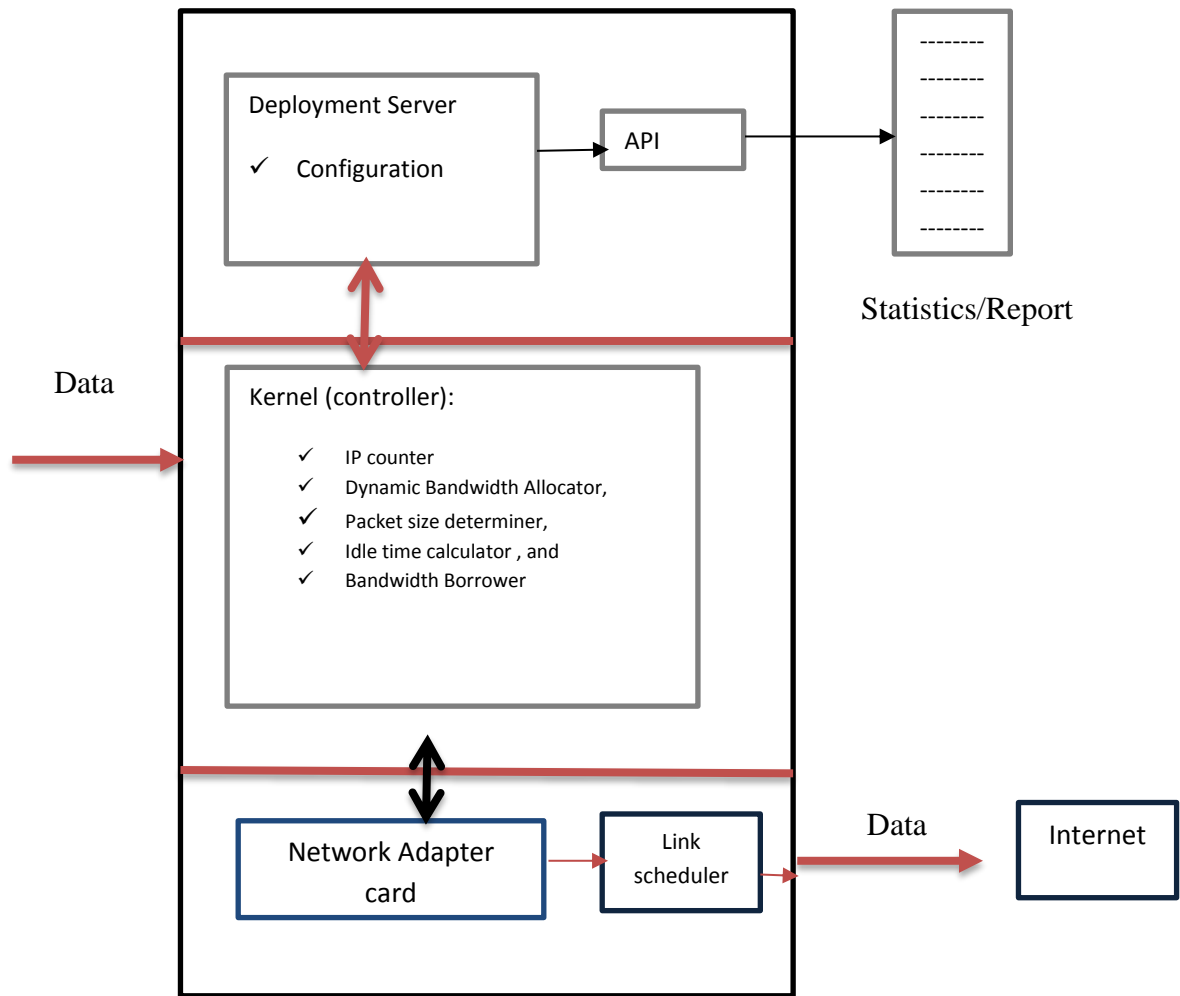


Figure [21] Bandwidth Allocation High Level Topology

Deployment Server is the Linux server where the traffic shaping and traffic monitoring is configured.

Bandwidth Borrower: if a user is configured with ceiling rate and if there is a bandwidth in the bucket then a user can borrow bandwidth to use beyond the GR.

Idle Time calculation, based on the SAWMILL log analyzer, a user could have more than 9 hours of session, but that doesn't mean he/she is requesting a constant bandwidth rate. So to release the allocated bandwidth to the bucket after it has been allocated, the algorithm calculates Update Time interval and if a packet is not requested in that time frame, the allocated bandwidth will be retrieved to the bucket.

Packet size: the algorithm must count the packet size to determine if a user is using only MR, for idle time calculation, GR, normal packet traffic flow, and CR, for bandwidth borrowing.

Figure 22 below shows the hierarchical token bucket structure used in the algorithm. The root of hierarchical token bucket class determines the place of HTB instance and every child will get the allocate bandwidth from the root (parent) class. Child classes are used to divide user into different group and assigned different set of bandwidth.

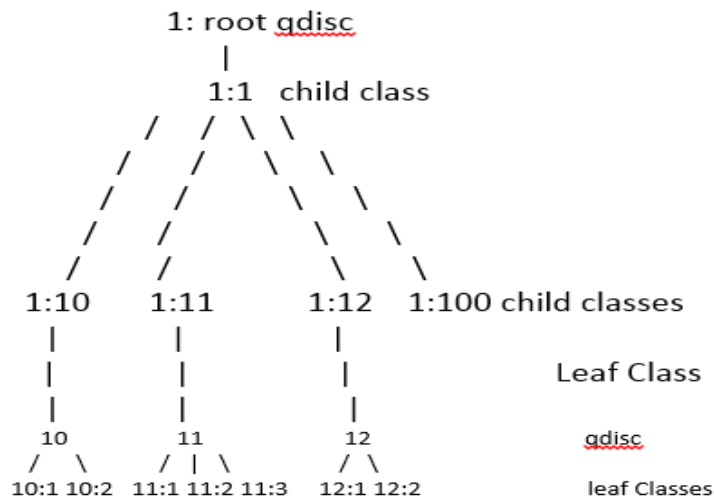


Figure [22] Hierarchical Token Bucket structure

5.7 Dynamic Bandwidth Allocation algorithm

Packet classifier: a packet classifier is used to classify packets into appropriate classes and each packets coming from that specific classes will get the minimum amount of bandwidth and will be configured with ceiling rate if necessary. Below is the pseudo code of a classifier:

```
BEGIN  
  
    GET a packet P passing to network-link  
  
    SET i= P.classID  
  
    INSERT P INTO traffic_class_queue[i]  
  
END
```

In any connection K, a user could be in any one of these states:

Non-connection: in this state, a user is not connected to the network and didn't request bandwidth from the bucket, so the dynamic bandwidth allocation algorithm is not activated.

Idle Connection: a user has been connected, sessions (links) has been created, but user's bandwidth demand is below the minimum bandwidth threshold set. At this state of connection, bandwidth residual is activated where idle and unused bandwidth is returned to the bucket.

Non-Greedy: at this state, a user has been connected, sessions have been created. The actual transmission rate is between minimum bandwidth rate and the GR. In this connection state, the algorithm monitors packet size for each given time and determines the connection state.

Greedy: in this connection state, a user is requesting a bandwidth above the GR continuously. That means the user needs to grow its bandwidth demand to its Ceiling Rate (CR). Based on the policy and configuration parameter set by a network administrator, bandwidth borrower is activated.

Unique IP counter Algorithm

To assign a guaranteed rate of bandwidth for each user, none repeated IP address must be known by the algorithm. Below is the algorithm used to count a unique IP address and will be used for bandwidth allocation later in a compiled dynamic bandwidth allocation algorithm.

Function: UniqueIP(srcIPAdd)

BEGIN

 GET P.ClassID();//calling packet classifier

 totalIP[];

 srcIPAdd();

 cntIPAdd=0;

 FOR (each P.ClassID())

 READ srcIPAdd(),

 IF !seen(srcIPAdd())

 totalIP() = srcIPAdd+1;

 ENDIF

 return srcIPAdd();

 ENDFOR

END

IP Packet size Determiner Algorithm

Each link created requires a certain amount of packet passing via network link to form sessions. A user without bandwidth management can generate packets that could congest and chock the network link. In Dynamic Bandwidth Algorithm, every packet must be known and appropriate action must be taken before the service gap has occurred.

Function: *PacketSize(srcIPAdd);*

BEGIN

Global Variable:

IPAdd = UniqueIP(srcIPAdd); //calling each Unique IP address

totalTrafficSize[srcIPAdd]=0;

FOR(each IPAdd)

 READ totalTraffic;

 totalTrafficSize[srcIPAdd]= HTTP_{traffic} + HTTPS_{traffic} + ICMP_{traffic} +
 POP3_{traffic} +.....N_{traffic}

ENDFOR

END

Timer

Timer is used to determine if the user session is in idle state. To determine if a user is in idle state the algorithm should record the session start time along with packet size requested. For this thesis, 2 minutes or above in using the bandwidth for lower than the minimum bandwidth set is consider an idle user and the bandwidth assigned to that user is collected back into the bucket. But timing should be determined based on resources and network infrastructure used for the university

network since asking the algorithm to calculate within a few second request high server CPU processing cycle. More, it requires further studies

Residual Bandwidth and allocation of Spare Bandwidth

After a Guaranteed Bandwidth rate is allocated for each user, the algorithm monitors the actual transmission rate r_k^n of a user in a given time interval n. If the r_k^n is less than MR in that time frame while there is an active session connections, then a user is considered to be in an idle state and the allocated bandwidth has to be returned to a bucket. Residual bandwidth includes spare bandwidth (unallocated), idle user's bandwidth and bandwidth left from being used by none-greedy user.

1. For every connection k, the required transmission in every nth interval update is:

$$\text{Actual transmission rate} = r_k^n \text{ for } \forall ki \in K \text{ where } ki \text{ is user connections}$$

Function : residualBandwidth();

BEGIN

GET UniqueIP(srcIPAdd);

GET PacketSize();

Global VARIABLES

T1 =CurrentSystemTime();

T2=NextCurrentSystemTime();

idelBandwdithRate=0;

unUsedBandwidtRate=0;

FOR (each UniqueIP(srcIPAdd))

IF(r_k^n (srcIPAdd) < MR(srcIPAdd)) THEN

INIT T1 = CurrentSystemTime();

FLAG time = 1;

READ NextCurrentSystemTime() as T2

IF(T2-T1 >=2 min)

idelBandwdithRate= unUsedBandwidtRate+idelBandwdithRate + GR(srcIPAdd)

FLAG time =0;

ELSEIF (r_k^n (srcIPAdd) < GR(srcIPAdd))

unUsedBandwidtRate= (GR(srcIPAdd)- r_k^n (srcIPAdd))

ENDIF

ENDFOR

residualBandwdith() = idelBandwdithRate + spareBandwdith;

return residualBandwidth();

END

Bandwidth Borrower Algorithm

Bandwidth borrower algorithm will be activated for those users who wish to extend bandwidth usage if there is bandwidth in the bucket, after allocating it to all active users, and if the class is configured to extend the bandwidth request beyond the actual bandwidth rate. A network administrator can configure a class of users with committed rate and ceiling rate. By ceiling rate, a user can extend the bandwidth utilization beyond the AR.

Function: BandwidthBorrower();

BEGIN

FOR(each *UniqueIP(srcIPAdd)*)

GET *PacketSize(srcIPAdd)*;

IF (r_k^n (srcIPAdd) > GR(srcIPAdd))

isset(CR())

r_k^n (srcIPAdd) = CR();

PASS *PacketSize(srcIPAdd)* TO *network-link*

ELSEIF (r_k^n (srcIPAdd) > CR())

PASS *PacketSize(srcIPAdd)* TO Queuing

ENDIF

ENDFOR

END

Actual Bandwidth Allocation Algorithm

Actual bandwidth is the amount of bandwidth rate allocated for each user and used in a normal condition. It is also called *Guaranteed Rate (GR)*. But if there is spare bandwidth and if a user is configured to expand its rate beyond the GR, then a user can borrow bandwidth. Determining the actual rate of bandwidth allocation depends on the policy formulated by the institution and a kind of resources a user is expected to access. Below is the algorithm that define the actual bandwidth allocation algorithm [28].

Function: BandwidthRate()

BEGIN

Global Variable.

READ P.ClassID

T1=CurrentSystemTime();

T2=NextCurrentSystemTime();

SET MR(srcIPAdd) = 50 kbit;

FOR(each *UniqueIP(srcIPAdd)*)

FOR(each T2-T1 \geq 2 mins)

IF(r_k^n (srcIPAdd) < MR(srcIPAdd))

Call residualBandwidth();

ELSE IF (r_k^n (srcIPAdd) > MR(srcIPAdd) && r_k^n (srcIPAdd) \leq GR(srcIPAdd))

THEN

r_k^n (srcIPAdd) = ConfirmPacket();

PASS ConfirmPacket() TO network_link;

```

        ENDIF
    ENDIF
ENDFOR
ENDFOR
    FOR(each UniqueIP(srcIPAdd))
        IF(  $r_k^n$  (srcIPAdd) > GR(srcIPAdd) && isset(CR()))
            call BandwidthBorrower();
        ENDIF
         $r_k^n$  (srcIPAdd) = AR (srcIPAdd) + BandwidthBorrower();
        PASS ConfirmPacket() TO network_link;
    ENDFOR
ENDFOR
END

```

Dynamic Bandwidth Allocation Algorithm:

Below is compiled algorithms that calls every single functions:

```
BEGIN

    GET P.ClassID();

    SET MR() = 50 kbps;

    GET PacketSize();

    numUsr= totalIP();

    FOR (i=1 TO numUsr())

        IF (PacketSize(i) < MR(i)) THEN

            Call packetResidual();

        ELSEIF(PacketSize(i) ≤ GR(i)) THEN

            PASS PaketSize(i) TO network-link

            call packetResidual();

        ELSEIF (PacketSize(i) >GR(i)) THEN

            CALL BandwdithRate();

        ENDIF

    ENDFOR

END
```

5.8 Prototype Implementation and Testing

The prototype for bandwidth management was implemented by writing script using traffic controller (**tc**) command available in the Linux kernel. The implementation module is depicted in figure 22.

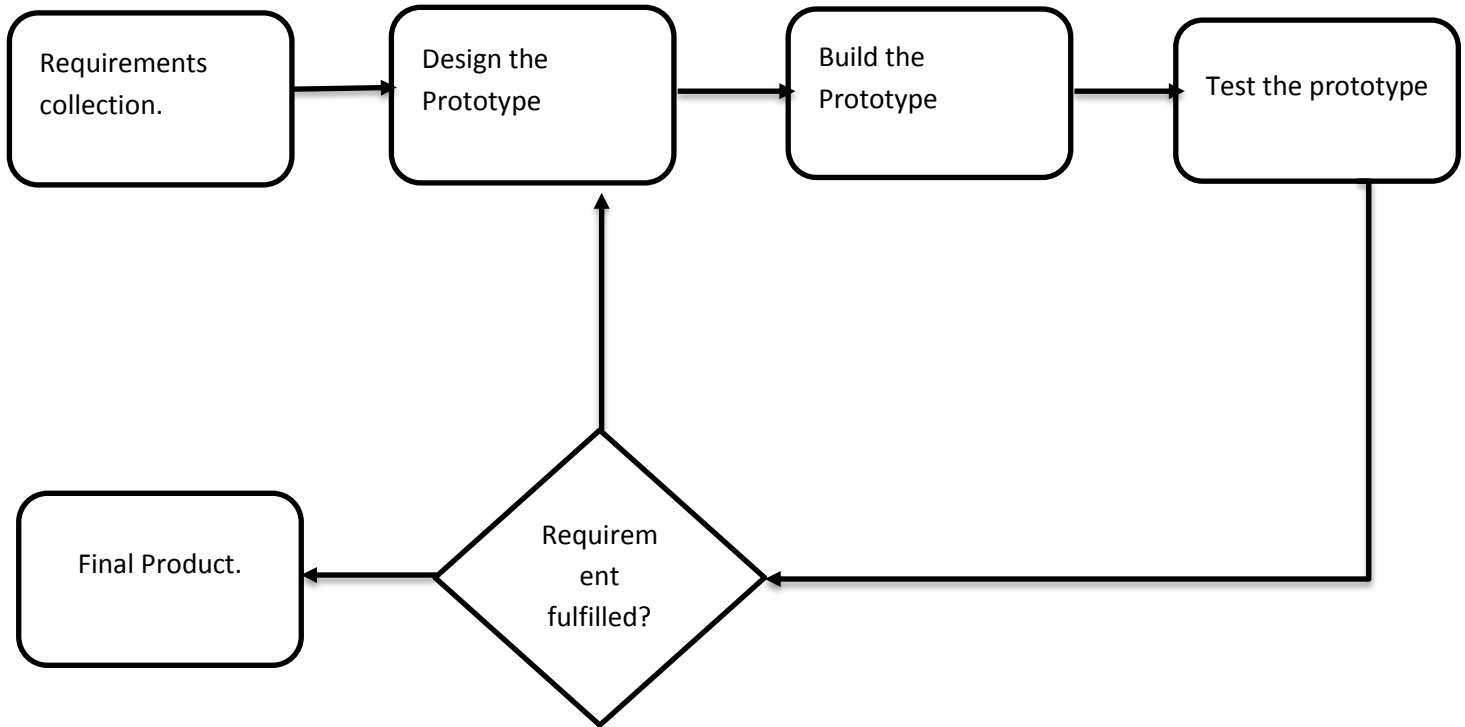


Figure [23] Implementation Model

To implement dynamic bandwidth allocation algorithm the following detail analysis must be performed, the administrator must measure and ensure; the ISP is living up to its deal in providing the subscribed bandwidth at all time, be able to identify those high bandwidth consumers, determine the minimum bandwidth requirement for web surfing, streaming and voice over IP and finally allocate the minimum bandwidth rate for every user who is joining the network and allow those users to extended to the maximum rate whenever there is reserved bandwidth in the bucket

after collecting idle and un used bandwidth from the user or if there is unallocated bandwidth in the first place.

5.8.1 Testing

The prototype was evaluated for bandwidth allocation per class and bandwidth borrowing from a parent class. The test bed environment was done on the emulated software, GNS3, which comprised one access switch, one core Switch, one windows 7, and Linux Operating system acted as a gateway between the internal network and Internet. Traffic was generated by accessing web contents, torrent files, YouTube and uploading a huge file to 4shared.com form a windows 7 machine integrated into GNS3.

5.8.1.1 Test Results before Algorithm Applied

Figure 23 shows that traffic captured before the algorithm was implemented. As it is shown a user with an IP address of 10.6.0.2 which belongs to student class and an IP with 10.6.32.2 from staff class managed to generate a traffic above 1 mbps.

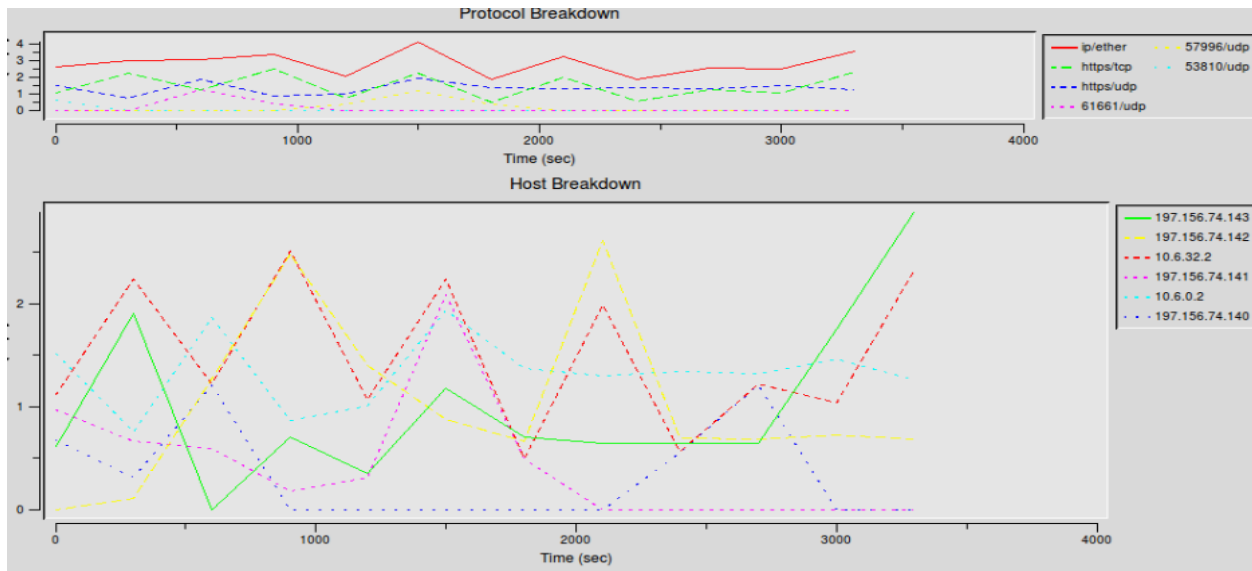


Figure [24] One Minutes Traffics before the Algorithm is Applied

Figure 25 below present the five minutes of network traffic from both class and they have a bandwidth usage of above 1 mbps.

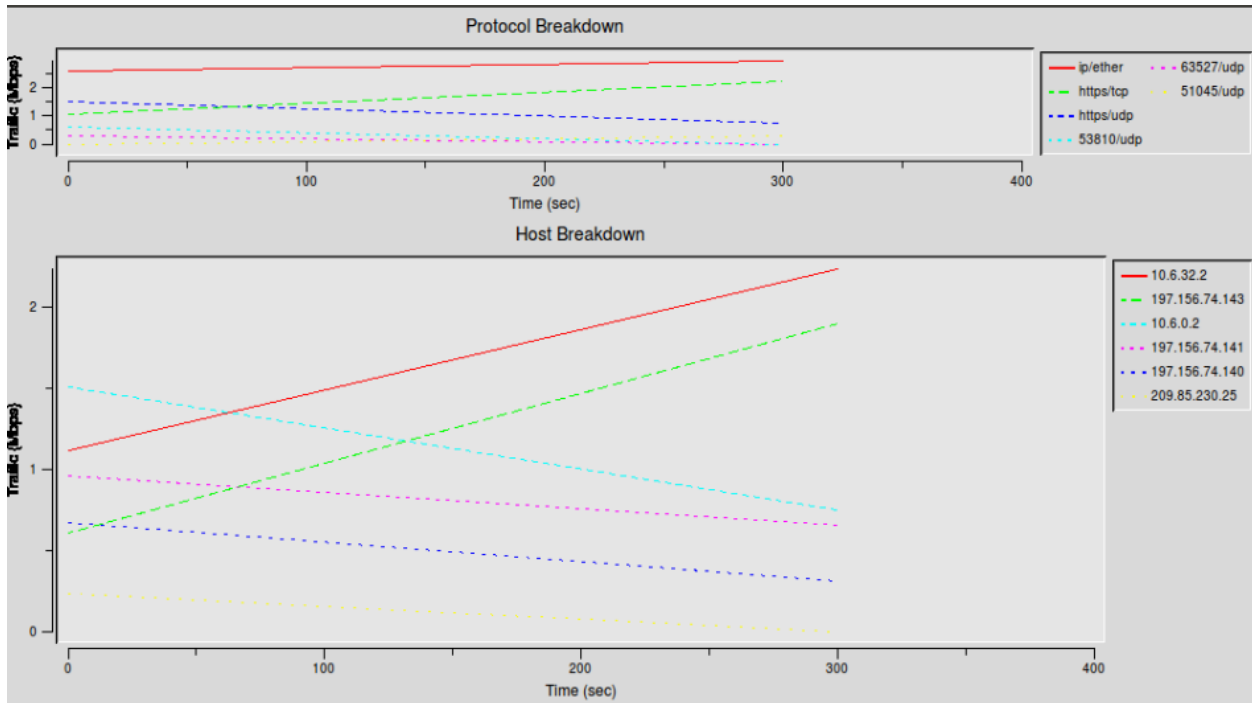


Figure [25] Five Minutes user Traffic before Algorithm applied

Using the BandwidthD, a traffic from the student group was recorded for both inbound and outbound. There are more outbound traffic than returning traffic and a single user generates an average traffic of 4 Mbit and peak of 10 Mbit.

(Top) 10.6.0.3 - Configure DNS to reverse this IP

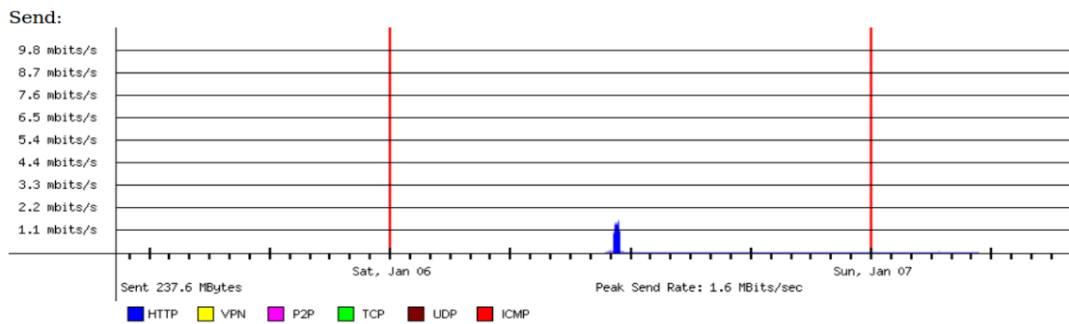


Figure [26] Inbound user traffic

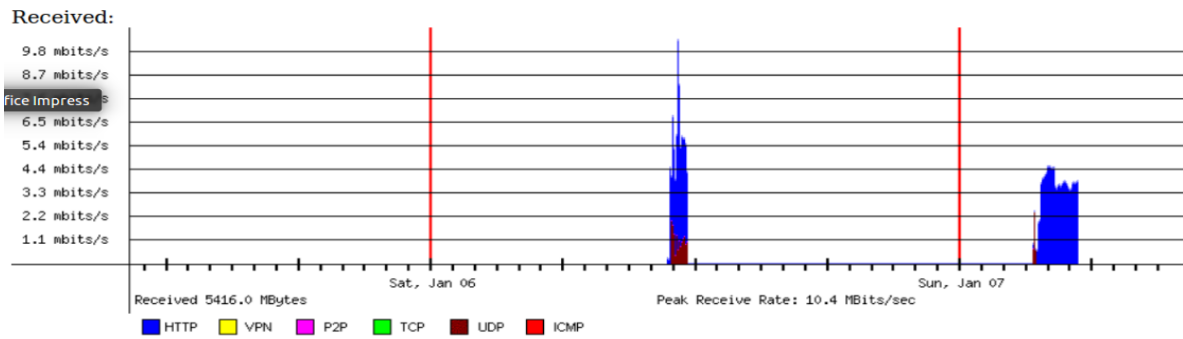


Figure [27] User Outbound Traffic

5.8.1.2 Testing of Bandwidth Allocation after Implementing the Proposed Algorithm

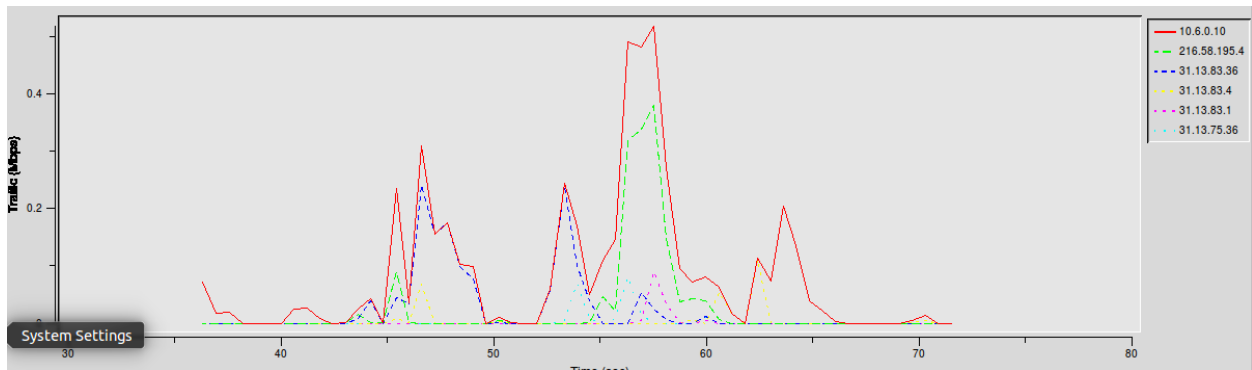


Figure [28] Evaluation of User Traffic from Student Class

As shown in the figure 28, a user in the class of student uses the committed bandwidth rate allocated to their respective class and extend the consumption to 512 which was configured as Ceiling rate.

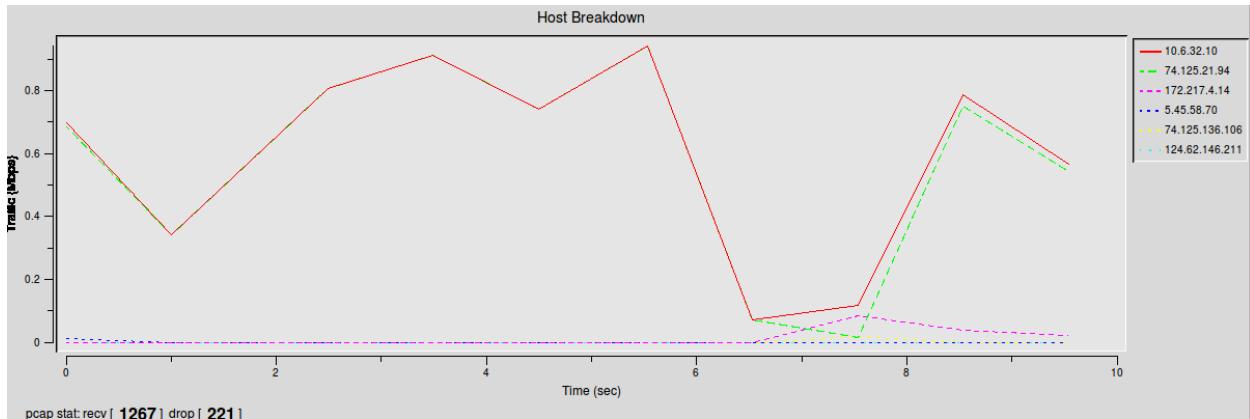


Figure [29] Evaluation of User Traffic from Staff Class

As shown in the figure 29, a user in the class of staff use the committed bandwidth rate allocated to their respective class and extend the consumption to 1 mbps which was configured as Ceiling rate.

5.9 Prototype Test Simulation Topology

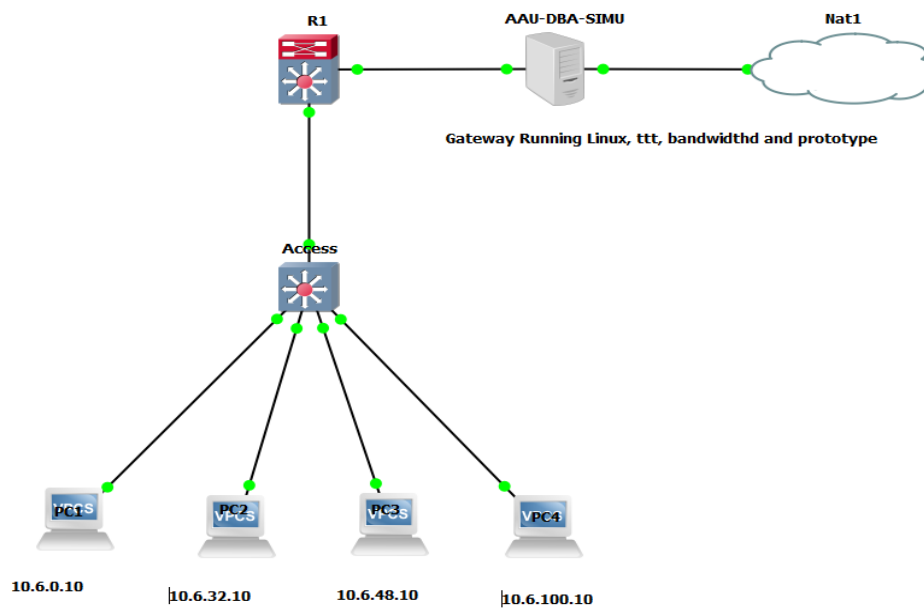


Figure [30] Prototype Test Simulation Topology

5.10 Summary

This chapter presented dynamic bandwidth allocation algorithm and result of prototype test. This chapter also review the concept of bandwidth control and proposed allocator for this thesis in order to provide an insight of how the bandwidth control works and also prototype design requirements was gathered based on the control concept. Evaluation of experiments was carried out on emulated network simulating AAUNet. Accordingly, the algorithm manage to limits the bandwidth utilization per users to a given amount and allows the user to extend bandwidth usage when they want if there is idle bandwidth in the bucket. It would be better if the algorithm manage to limit the bandwidth utilization based on the applications, but due to the vast nature of the applications the scope will be so wide which requires money and human resources.

CHAPTER SIX

DISCUSSION OF FINDINGS, CONCLUSION, AND RECOMMENDATION

6.1 Discussion of Findings

This thesis focuses on developing demand based dynamic bandwidth allocation algorithm. By demand based, if a user is configured to borrow bandwidth, he/she can borrow from the pool and if user is not using the connection then the allocated bandwidth is returned back to the pool.

This chapter focuses on developing a dynamic bandwidth allocation algorithm for Addis Ababa University network, AAUNet. It also presents the Conclusion and forwards recommendations for future work.

The result of the study shows that there are unbalanced usage of internet between users in the university. Due to this fact only a few users consumed most of the bandwidth and starve others. Among the 12285 users analyzed from 6 kilo, 5 kilo and 4 kilo campuses, 10 users utilize 2.7% of the total bandwidth which accounts 298.31 GB of data. To solve this issue a dynamic bandwidth allocation algorithm was developed.

6.2 Conclusion

Proper bandwidth management is key for effective and efficient utilization of bandwidth and providing better services since it is not feasible to meet the increasing demand for bandwidth by adding more and more.

In this thesis a dynamic bandwidth allocation algorithm was developed and script was written on Linux kernel to test the algorithm. Interclass bandwidth borrowing was implemented to prevent bandwidth wastage by an idle user and unused bandwidth. Tests were conducted to evaluate the prototype using emulation software. The result shows that the algorithm managed to keep the users

to use the allocated Internet Bandwidth only. Since the bandwidth allocation has a minimum set that permit every user to access Internet when they joined to the network and maximum bandwidth which allows them to use the higher than the actual bandwidth allocation when there is a bandwidth in the bucket, the result show that user only uses to the maximum allocation rate even when they put large amount of files to download using peer-to-peer and online steaming.

6.3 Critical Review and Reflection

The main objective of the study was to develop dynamic bandwidth allocation algorithm and evaluate it with prototype. Applying the prototype on working equipment has an adverse impact on the performance of the system. So emulated network and Open source software was used instead. The simulation software has real world environment equivalence. Since those tools used to test the algorithm is free, a system and network administrator can see the effect of the algorithm before applying it on real world.

In order to design an efficient and cost-effective bandwidth allocation algorithm, there were question that needed to be answer at the end of the thesis work. Therefore, in this section we will evaluate how much the question was answered.

After analyzing the live captured data on the edge of the AAUNet network using solarWinds and PRTG, the Internet traffic that is coming from the ISP(EthioTelecom) has a fair performance, but the Service provider didn't provide the full bandwidth that was agreed with its client. The proxy logs analysis shows that there are unbalanced Internet utilization between the users in the campus that a single user have the ability to generate gigabytes of Internet traffic within the day using peer-to-peer, YouTube, live streaming or any other bandwidth greedy applications while other users are struggled to access their emails and brows on the web. The challenge to control those high

bandwidth utilizer is due to the dynamic nature of applications on Internet which makes it challenging tasks for network administrator to manage. In this thesis, dynamic bandwidth allocation algorithm was designed by classifying users into group and allow them to access defined amount of bandwidth with the ability to extend the utilization of bandwidth when there is a free bandwidth in the bucket.

6.4 Recommendation

In the process of carrying out this study, a single user generates a lot of traffic and has longer sessions, and some of the packet destination is unknown, it is better if the packet flows analysis, and information security audit is performed which is not in this scope. During the prototype test, the testing was done in an emulating software, GNS3 since using the hardware device to test is very much difficult. It will be best if the university test the algorithm on real-world environment observe the effect of the algorithm.

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APPENDIX

Complete script for traffic allocation

```
#!/bin/sh

# Download traffic control

IP1=10.6.0.10

IP2=10.6.30.10

IP3=10.6.48.10

IP4=10.6.100.10

DEV=eth0

#

tc qdisc del dev $DEV root

#

tc qdisc add dev $DEV root handle 1: htb default 100

#

tc class add dev $DEV parent 1: classid 1:1 htb rate 10240Kbps ceil 1250Kbps

tc class add dev $DEV parent 1:1 classid 1:10 htb rate 256Kbps ceil 300Kbps

tc class add dev $DEV parent 1:1 classid 1:11 htb rate 300Kbps ceil 1024Kbps

tc class add dev $DEV parent 1:1 classid 1:12 htb rate 128Kbps ceil 128Kbps

tc class add dev $DEV parent 1:1 classid 1:100 htb rate 100Kbps ceil 100Kbps
```

```

#
tc qdisc add dev $DEV parent 1:10 handle 10: sfq perturb 10
tc qdisc add dev $DEV parent 1:11 handle 11: sfq perturb 10
tc qdisc add dev $DEV parent 1:12 handle 12: sfq perturb 10
tc qdisc add dev $DEV parent 1:12 handle 100: sfq perturb 10
#
if [ ! -z $IP1 ]; then
tc filter add dev $DEV protocol ip parent 1:0 prio 1 u32 match ip dst "$IP1" flowid 1:10
fi
if [ ! -z $IP2 ]; then
tc filter add dev $DEV protocol ip parent 1:0 prio 1 u32 match ip dst "$IP2" flowid 1:11
fi
if [ ! -z $IP3 ]; then
tc filter add dev $DEV protocol ip parent 1:0 prio 1 u32 match ip dst "$IP3" flowid 1:12
fi
if [ ! -z $IP4 ]; then
tc filter add dev $DEV protocol ip parent 1:0 prio 1 u32 match ip src "$IP4" flowid 1:100
fi
#
# Upload traffic control
#
DEV=eth1

```

```

#
tc qdisc del dev $DEV root

#
tc qdisc add dev $DEV root handle 1: htb default 100

#
tc class add dev $DEV parent 1: classid 1:1 htb rate 1250Kbps ceil 1250Kbps
tc class add dev $DEV parent 1:1 classid 1:10 htb rate 256Kbps ceil 512Kbps
tc class add dev $DEV parent 1:1 classid 1:11 htb rate 300Kbps ceil 1024Kbps
tc class add dev $DEV parent 1:1 classid 1:12 htb rate 128Kbps ceil 128Kbps
tc class add dev $DEV parent 1:1 classid 1:100 htb rate 100Kbps ceil 100Kbps

#
tc qdisc add dev $DEV parent 1:10 handle 10: sfq perturb 10
tc qdisc add dev $DEV parent 1:11 handle 11: sfq perturb 10
tc qdisc add dev $DEV parent 1:12 handle 12: sfq perturb 10
tc qdisc add dev $DEV parent 1:12 handle 100: sfq perturb 10

#
if [ ! -z $IP1 ]; then
tc filter add dev $DEV protocol ip parent 1:0 prio 1 u32 match ip src "$IP1" flowid 1:10
fi

if [ ! -z $IP2 ]; then
tc filter add dev $DEV protocol ip parent 1:0 prio 1 u32 match ip src "$IP2" flowid 1:11
fi

```

```
if [ ! -z $IP3 ]; then
```

```
tc filter add dev $DEV protocol ip parent 1:0 prio 1 u32 match ip src "$IP3" flowid 1:12
```

```
fi
```

```
if [ ! -z $IP4 ]; then
```

```
tc filter add dev $DEV protocol ip parent 1:0 prio 1 u32 match ip src "$IP4" flowid 1:100
```

```
fi
```

Configuring Ubuntu 14.04 software as Router and DNS Server for Prototype Deployment

/etc/sysctl.conf - Configuration file for setting system variables

See /etc/sysctl.d/ for additional system variables.

See sysctl.conf (5) for information.

Functions previously found in netbase

Uncomment the next two lines to enable Spoof protection (reverse-path filter)

Turn on Source Address Verification in all interfaces to

prevent some spoofing attacks

net.ipv4.conf.default.rp_filter=1

net.ipv4.conf.all.rp_filter=1

Uncomment the next line to enable TCP/IP SYN cookies

See <http://lwn.net/Articles/277146/>

Note: This may impact IPv6 TCP sessions too

net.ipv4.tcp_syncookies=1

Uncomment the next line to enable packet forwarding for IPv4

net.ipv4.ip_forward=1

```
# Uncomment the next line to enable packet forwarding for IPv6

# Enabling this option disables Stateless Address Autoconfiguration
# based on Router Advertisements for this host

    net.ipv6.conf.all.forwarding=1

#####

# Do not accept ICMP redirects (prevent MITM attacks)

    net.ipv4.conf.all.accept_redirects = 0

    net.ipv6.conf.all.accept_redirects = 0

# _or_

# Accept ICMP redirects only for gateways listed in our default
# gateway list (enabled by default)

    net.ipv4.conf.all.secure_redirects = 1

#

# Do not send ICMP redirects (we are not a router)

    net.ipv4.conf.all.send_redirects = 0

#

# Do not accept IP source route packets (we are not a router)

net.ipv4.conf.all.accept_source_route = 0

net.ipv6.conf.all.accept_source_route = 0

#

# Log Martian Packets
```

```
net.ipv4.conf.all.log_martians = 1
```

```
#
```

```
iptables -t nat -A POSTROUTING -o eth1 -j MASQUERADE
```