Faculty of Computing and Information Management

INTERNET BANDWIDTH MANAGEMENT FOR TERTIARY INSTITUTIONS

By

KITHINJI JOSEPH

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A Project Report submitted in partial fulfillment of the requirements for the award of the Masters degree in data communication in the Faculty of Computing and Information Management of KCA University.

DECLARATION

I Joseph Kithinji do hereby declare that this Project Report is my original work and has not been submitted for any other degree award to any other University before.

Signed: .... Date: ....

Joseph Kithinji

Reg No.12/00769

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APPROVAL

This Project Report has been submitted with the approval of the following supervisor.

Signed: .... Date: ....

Dr. Alice Njuguna.

Faculty of Computing and Information Management

KCA University.

DEDICATION

This research report is dedicated to all my loved ones.

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LIST OF ABBREVIATIONS AND ACRONYMS

MTTI	Meru Technical Training Institute
TCP	Transmission control protocol
KENET	Kenya education network
JANET	Joint Academic Network
TENET	Tertiary Education Network
WRED	Weighted Random Early Detection
UDP	User Datagram Protocol
LAN	Local Area Network
HTB	Hierarchical Token Bucket
CPU	central processing unit
OSI	open system interconnection
DPI	Deep Packet Inspection
FIFO	First in First Out
UKERNA	United Kingdom Education and Research Networking Association
UBM	Unified Bandwidth Management.

ABSTRACT

The internet has become a key resource in all learning institutions for research and communication. These learning institutions are also experiencing high student's populations which have in turn has led to more demand for internet bandwidth. The high students' population makes the overall bandwidth available shrink leading to slow internet connection making internet an ineffective an academic resource. Many institutions respond to slow internet connection by buying more bandwidth which is uneconomical with bandwidth being an expensive resource. This study was undertaken to find a way to optimize and make efficient use of available bandwidth. In particular the study research was aimed at designing and implementing a bandwidth manager prototype suitable for tertiary institutions in Kenya. The requirements for the prototype were based on the bandwidth management needs of Meru Technical Training institute network. The prototype was implemented using the tools available in Ubuntu 12.0LTS Linux and evaluated on a test bed emulating the Meru Technical Training institute network. The prototype was evaluated on traffic classification, bandwidth allocation and bandwidth sharing. The findings obtained provide proof that the prototype can be used for bandwidth management. Suggestions for further research were given such as testing the prototype on a real world network, testing the effects of scalability on bandwidth management and establish the effect of bandwidth on memory and C.P.U usage by network devices.

CHAPTER ONE

INTRODUCTION

1.0 Background of the Study

The history of Online education dates back to the 1960s when technicians at the university of Illinois developed the programmed logic for automated teaching operations (PLATO).PLATO was used by students to remotely access lessons, tests and other educational materials from remotely located instructors via a terminal. In 1969 the United States department of defence developed the advanced research projects agency network (ARPANET) which eventually grew into the internet. In the 1970s the internet relay chat was invented which allowed real time one on one conversation. Following this idea, in 1989 Time Bernas-Lee developed the worldwide web which consisted of interconnected servers that stored web pages. After the development of the world wide web, the University of Phoenix introduced distance learning for working adults in the late 1989.In the 1990s the internet gained more popularity with the introduction of the Mosaic browser by the national centre for supercomputing applications. This mosaic browser provided a user-friendly interface for users to access the internet. In the 2000s with advancements in audio and video broadcasting, many education institutions adopted online learning (Van, Veldsman & Jenkins, 2008). According to Odinma et al (2008), by 2007 over 4500 colleges in America were offering online education to some degree. In its development, the internet has been playing a vital role in research and educational communications. This is the reason why many education institutions are making continued efforts in providing better internet connectivity for its students and lecturers. In the developed nations internet access is adequate, but in the developing nations, internet is still an expensive resource due to poor infrastructure.Miniwatts (2009) observed that Nigeria has the second largest number of internet users in Africa, with an internet penetration of 7.4%.Though the situation in expected to change in the near future due to the arrival of the international fibre optic cable, cross country connectivity still remains a challenge. For education institutions to benefit from the internet, effective management of the resource will need to be implemented (Miniwatts, 2009).A learning institution network plays an important role in the core mission of the institution. Network applications such as cluster computing, digital libraries, IP telephony and IP based distance learning are increasingly becoming critical services and they must be delivered with the same degree of reliability as any other utility. Many education institutions set up significant amount of their budgets towards increasing their bandwidth and upgrading their networks. A number of platforms exist for providing free publications such as UNFAOs, AGORA and WHOSs HINARI projects, PERI, PIOs and SCiDevNet.Such resources are of great importance to researchers in learning institutions as is evident from the user feedback they receive. Bandwidth management could be employed as a coping strategy to those institutions with poor infrastructure and low bandwidth connections. The increasing student's enrolments, integration of ICT in teaching, Learning and Research will require more bandwidth and cheaper ways to access it in the coming years. For many years bandwidth management has been implemented on the network infrastructure hardware and software. The network infrastructure hardware and software has been traditionally implemented as part of the overall network infrastructure. In response to network level approaches software vendors incorporate in their software bandwidth throttling mechanisims.These mechanisms have proven not to be very effective on their own since they are not flexible. Individual institutions donors are providing ongoing support to institutions for upgrading their equipment and network. This support is channeled through local initiatives and organizations such as the African virtual universities, the African association of universities and national research and educational networks (Steiner, Nyasha, Mike & Gakio, 2005). To ensure cheap access to internet in higher institutions of learning in Europe, many countries have established national research and education networks for higher learning institutions. In US for example, universities join networks established by the national science and foundation so as to collectively bargain for cheaper bandwidth. JANET is a network platform that connects UK research and education institution, it ensures that it members use bandwidth management and has an advisory service to help institutions achieve proper bandwidth management. Research done by JANET has shown that if an institution had a slower connection, internet access would still function, however if the connection was increased and management removed, useful access to the internet would decrease immediately (Habler & Jackson, 2010).Similar initiatives are found in Africa; In 1992 the Regional Information Society Network for Africa was initiated as a framework of UNESCOs support to improve academic and public sector networking. In May 2002 in an effort to promote efficient use of internet bandwidth resource towards improving education, Regional Information Society Network for Africa held a workshop on the role of internet in education and how to use it effectively. In the first East African Business summit held in Nairobi on November 2002, the East African submarine cable system idea was conceived to make internet affordable in east Africa. Initially the internet in east Africa was expensive because it relied on satellite communication (Camilius, Juma & Lazaro, 2010). In South Africa, Tertiary Education Network (TENET) a national education network forms a team where South African Education institutions can negotiate for better bandwidth price rates with national telecommunications operator Telekom. TENET is a non-profit organisation that acts as an agent for the higher education sector in South Africa that bargains for a single set of pricing packages for bandwidth with the Telekom. TENET is not involved in network management but only negotiates and manages contracts with the national Telekom on behalf of the education institutions. TENET makes the internet bandwidth affordable than it would be at full commercial rates, and reduces the cost of collaboration among education institutions since traffic does not have to move outside the TENET network. Through TENET higher education institutions are able to buy bandwidth below the commercial rates. In addition higher education institutions are allowed to use bandwidth above their permitted committed information rate if it is available(Beda, Francisco, Tusubira, Mamman & Tolly,2008).In 1997, Cameroon launched the Cameroon inter-university network which connects 6 states universities and provides internet connectivity and IP telephony. In 1999 the Kenya education network was formed with an aim of providing internet connectivity to education institutions and facilitate teaching and learning over the internet. Member institutions are connected directly to a national backbone (Jumbonet) using Kenstream digital leases lines. In 2002, Senegal established the university of Dakar network to share campus information technology with other education institutions with the support of the French government. In Africa some individual universities have made noticeable efforts in an effort to provide affordable internet connection. These Countries include Ghana, through the Ghana research network which through grants from the Danish government was able to establish a very small internet initiative terminal (VSAT) connection to the University of Ghana with a bandwidth capacity of 128Kbps for uplink and 512 Kbps for downlinks. In 2007 the scan-ICT project was launched in Gambia which was aimed at determining the level of internet use in the countries education sector and was to make proposals for reducing the cost of access to internet. In 2006, Aptivate conducted a survey to access bandwidth management issues with the Kenya education network. The survey found that some institutions are limiting student internet access to five hours in a week, one that connected computer labs for computer science students only and another that had been forced to take extreme measure of cutting off student's access entirely. But this measures can reduce the impact of internet could have in learning institutions (Rosenberg, 2008).Fabrice, Cefn and Mark (2009) believe that the emergence of new internet applications and services makes it hard for network operators to predict or categorize uses of the network. In the recent years bandwidth growth on the internet has been in the rates of excess of 50%.This growth is more prevalent in developing countries and varies greatly by country and by geographic region. Video streaming and download cloud services and mobile data services are driving bandwidth demand (Rosenberg, 2008). This dissertation reports on the study carried out on efficient internet bandwidth management at Meru Technical Training Institute.Meru Technical Training Institute is a Tertiary institute located in Meru County, Kenya. The institute implements a static bandwidth management system using cyber roam. This technique targets a specific level of packet activity as its desired result. The implementation involves a client side or server side setting that gates the amount of packet traffic generated or accepted at preconfigured levels. In most cases the pipe itself must be statically configured or declared. In this model there is no real-time awareness of available bandwidth and consequently no reaction based on availability. The institute has been experiencing low internet connection especially during the working hours that is between eight in the morning and six in the evening. In order to optimize bandwidth in network, a bandwidth management scheme must incorporate some form of activity level monitoring and take advantage of these periods of inactivity to adjust bandwidth to where it is mostly needed (Kumar et al, 2010). The proposed method will provide efficient utilization of internet bandwidth over the network.

1.1 Source of problems in Bandwidth Management

Steiner et al (2005) point out the major challenge for efficient bandwidth management and optimization as being the high demand for bandwidth. The available bandwidth in tertiary institutions is not enough to meet user demands and to support optimal usage. The increased student populations and changing patterns in internet usage continue to generate resource and administrative challenges to network administrators. Eguzo et al (2013) describe lack of a policy framework for guiding the usage of internet bandwidth as a hurdle to bandwidth management. Eguzo et al (2013) continue to affirm that a policy is an important component of any bandwidth management approach since it provides a framework for defining how network resources should be used and how technical solutions should be implemented. Without a policy, many of the bandwidth implementation strategies end up failing. Another major hurdle to bandwidth management is lack of technical skills by network administrators. This has been an issue since most bandwidth approaches will eventually require a technical implementation. This combined with inadequate hardware resources for internet access make implementing technical solutions impossible. Pati (2007) affirms that in order for any bandwidth management solution to be effective an integrated approach should be used. That is a combination of policy and technical solution. Absence of one these would make bandwidth management ineffective if not impossible.

1.2 Parameters for Bandwidth Management

Pallavi and Vijay (2012) bandwidth speed as one of the most important parameter of bandwidth that can be managed for efficient usage. By limiting the speed available to users, Pallavi and Vijay (2012) believe that network administrators are able to prevent network performance deterioration arising from abuse of the network. Users can be allocated a committed rate without an option of getting more unless there is idle bandwidth.Muirzah and Hafizoah believe that access to bandwidth can be managed to optimize bandwidth in the network .This can be done by use of an SSID which a user is required to produce incase he/she wishes to access network resources. This would solve the problem of having congestion resulting from illegitimate traffic.

1.3 Definition of terms

Bandwidth-this is the amount of traffic that a given link can transmit within a certain period of time (Snehalatha, Julia &Rodrigues, 2013).

Bandwidth management- this is the process of controlling traffic on a network link in an effort to avoid bandwidth wastage (Dhaini, Assi & Shami, 2008).

Adaptive bandwidth management-this is the process of allocating bandwidth based on the current needs of network users (Dhaini, Assi & Shami, 2008).

Token-permission to transmit one bit of data (Jiang, Zhuang, Shen & Bi, 2011).

1.4 Statement of the problem

With many education institutions increasingly making use of internet on a daily basis, the demand for bandwidth is outstripping supply. The demand for bandwidth within education institutions is on a constant rise making the available bandwidth to be inadequate to support users. This demand is being driven by increase in student's population and use of bandwidth intensive applications (Sharma, Kumar & Thakiu, 2011).

Many institutions respond to slow internet connections by buying more bandwidth and upgrading the network infrastructure. However these are costly solutions, and may only solve short-term needs. With more bandwidth available users tend to use more which causes the overall available bandwidth to shrink (Steiner, Nyasha, Mike & Gakio, 2005). As the demand for bandwidth increases, the need for efficient bandwidth management strategies becomes a necessity if proper service provision is to be maintained. Absence of bandwidth management strategies leads to inappropriate use of existing bandwidth and provides avenues for bandwidth wastage (Eguzo, Igweonu & Robert, 2013)

To address the problem of bandwidth wastage and ensure efficient bandwidth utilization, this study proposes a bandwidth management prototype for dynamic bandwidth allocation in tertiary institutions network.

1.5 Aim of the study

The main aim of this study is to develop a bandwidth manager prototype to achieve efficient usage of internet bandwidth in Tertiary institutions

1.6 Specific objectives

1. To determine the status of internet connectivity in tertiary institutions that influence efficient utilization of internet bandwidth in tertiary institutions.
2. To determine bandwidth management strategies used in tertiary institutions in an effort of providing efficient utilization of internet bandwidth.
3. To determine challenges faced by tertiary institutions in implementing efficient utilization of internet bandwidth.
4. Develop a bandwidth management prototype that will achieve efficient utilization of internet bandwidth in tertiary institutions.

5. Implement the bandwidth manager prototype.
6. Test the prototype for bandwidth management for efficient utilization of internet bandwidth.

1.7 Research questions

1. What is the current status of internet connectivity in tertiary institutions that is leading to inefficient usage of internet bandwidth?
2. What methods of bandwidth management are used in tertiary institutions?
3. What challenges are tertiary institutions facing in an effort to manage bandwidth?
4. How effective is the proposed prototype in managing bandwidth for efficient utilization?

1.8 Significance of the study

This study is aimed at developing a dynamic bandwidth management prototype for efficient utilization of internet bandwidth for tertiary institutions in Kenya. The results of the study should lead to the development of a prototype for dynamic bandwidth management. It is hoped that the results of the study will make tertiary institutions authorities realize that effective bandwidth usage will be greatly facilitated by the formulation and implementation of an institutional bandwidth management strategy. The implementation of the bandwidth management prototype by tertiary institutions will lead to efficient utilization of internet bandwidth by allocating, limiting and sharing bandwidth. In addition the findings of this research study can be used as a foundation base for further research.

1.9 Scope of the study

This project is limited to implementing a bandwidth manager prototype for deployment at the perimeter of Meru Technical Training institute network. The design is based on open-source tools available on the Linux operating system. Therefore only bandwidth management techniques that are applicable at the Meru Technical Training Institute network are reviewed. The prototype will be limited in managing internet bandwidth since the local bandwidth is abundant. Although the design is based on the Meru Technical Training Institute network, it is generic enough to be applicable in similar networks.

1.10 Organization of the thesis

This report comprises of six chapters, chapter one discusses how bandwidth management is done around the world, aim of the study, objective of the study, motivation of the study and scope of the study. Chapter two discusses the various approaches of bandwidth management and implementation. Cisco routers and Linux are discussed as the most convenient implementation approaches for tertiary institutions. Chapter three describes the evolutionary prototyping methodology used together with the tools used. Chapter four describes the design of the major components of the prototype. Chapter five presents the results of the study of Meru Technical training institute and the prototype testing. Chapter six presents the discussions and conclusions of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Most routers provide only best effort services and packets are treated in first in first out manner. Traditionally routers treat all the packets without any guarantees in a best effort model. In this model the router delivers packets without nay performance guarantees. On a shared network link, this model allows users to transmit packets through the network without any limitaitions.This means that the performance of a network relies not only on the capacity of the link, but also on the amount of traffic each user puts into the network link. This means a single user running bandwidth intensive applications can consume a large portion of bandwidth, thus starving other users (Snehalatha, Julia & Rodrigues, 2013).Okonigene et al (2011) believe that the need for optimal usage and quality of service requires new methods of packet handling.Dhaini, Assi and Shami(2008) propose dynamic bandwidth management as a technique. This technique adjusts bandwidth attached to a particular user over a time. This is done by monitoring user traffic patterns then allocating the available user traffic to accommodate this traffic to accommodate this traffic. Dynamic bandwidth management scheme tracks a users behavior over a long time and therefore the user cannot increase the bandwidth usage to a great extent over short time without hitting the upper bandwidth limit set by the allocation algorithim.In a dynamic management scheme, on one hand if the user requests for more bandwidth, the management scheme will associate more network resources with the user, on the other hand if the particular user reduces the amount of traffic he or she is using on long term basis ,the algorithm will reduce the amount of network resources that had been associated with that user(Dhaini,Assi & Shami,2008).

2.2 Network management and traffic control

2.2.1 The transmission control protocol

Pati (2007), describes TCP as the backbone of the internet.TCP provides a reliable end to end connection for traffic transmission irrespective of the status of the medium used in a network. This makes TCP connection oriented.TCP is also a reliable protocol since any data transmitted over the TCP is delivered accurately in the correct sequence and error free. The sequencing of packets is achieved by assigning a sequence number to each packet. These sequence number enables the destination node to accurately re-order any packets that arrive out of sequence.TCP has also a number of features that assist in bandwidth management such as flow control and congestion control(Pati,2007).

2.2.1.1 TCP congestion control

With TCP being connection oriented protocol, this means that there is always a connection between the source and destination nodes. The destination node sends acknowledgement packets to the destination indicating the reception of the packets and the duration taken to reach the destination. If the source does not receive the acknowledgement after transmitting it assumes that the link is congested and therefore ceases to send the data. This essentially leads to reduction of data being transmitted. Traffic shaping techniques can take advantage of this by deliberately dropping packets which in turn makes the transmitting node to drop its transmission rate easing congestion in the network (Al-Manthari, Nasser & Hassanein, 2009).

2.2.1.2 TCP congestion avoidance mechanisms.

When congestion is detected in a network, TCP reduces the transmission rate. This is achieved by congestion avoidance algorithms on the nodes interface that drop packets causing TCP to retransmit at a slower speed by use of sliding window control protocol. Sliding window protocol is a flow control technique that tries to reduce congestion by matching the speed of the sender to that of the receiver. This ensures that the sender does not overwhelm the receiver with data.TCP uses the sliding window protocol to detect signs of congestion before it happens by increasing or reducing the load in the network accordingly. The sliding window flow control protocol achieves flow control by receiver sending a window back to the sender. The size of the window informs the sender of how much data to send. If the receiving node does not send a window, the sender interprets these as a sign of congestion and reduces the rate of transmission. The sliding window protocol also uses the speed at which acknowledgements are sent from the receiver to gauge the level of network load and adjust the amount of data to be sent accordingly. The sliding window protocol specifies a congestion window which is derived from the rate at which the source receives acknowledgment packets (Pati, 2007).Jiang, Zhuang, Shen and Bi (2011) describe this derivation in two stages. The first stage is known as slow start, where the source begins by setting the congestion window to one or two packets. The source then increments the window by one each time an acknowledgement is received, eventually doubling the window every round. This continues until packet loss is detected. At this point the source moves to the second stage. At the congestion avoidance stage TCP uses two algorithms; one of the algorithms is random early detection which drops packets from any outgoing traffic flows at random when the interface buffer fills to capacity. This ensures that all TCP flows that pass through the interface will reduce in speed. Jiang et al (2011) believe that this characteristic of TCP maintains equity in the traffic that is discarded. The second algorithm used by TCP at congestion stage is weighted random early detection (WRED).WRED implements weights when it comes into dropping packets. RED uses RED to discard packets but assigns weights to each flow so that more or less packets can be dropped from a particular flow. This makes it possible to specify a particular rate of transmission for that flow.

2.2.1.3 TCP flow control

TCP implements flow control via feedback based flow control and rate based flow control. In feedback flow control, the destination node sends information back to the source node, giving it permission to continue sending or informing the source on how it is coping with the traffic. In rate based flow control, the protocol is used to limit the rate at which the source can send data. This requires no feedback from the destination. Both methods lead to the data rate of the source node to be reduced either to the rate at which the destination node can process packet it’s or to a rate set by the sending protocol. This flow control ensures that end devices are not overwhelmed by packets. However TCP does not have the capability to distinguish between services, interfaces and protocols. This limitation makes TCP not to be useful in bandwidth management technologies (Liu, Cai & Shen, 2008).

2.2.2 The user datagram protocol (UDP)

UDP allows data to be sent without a connection having been established making UDP a connectionless protocol. Data is encapsulated in datagram then sent to the destination without the regard if the destination is ready.UDP offers the best effort delivery of datagrams.Since no acknowledgements are sent to the transmitting device there is no chance of retransmission in case the datagram's are dropped by one of the intermediate devices. In addition the UDP header does not have a sequence number and therefore the destination node has no way of knowing in what order the packets received are supposed to be. This makes UDP more appropriate for transmissions that do not require quality of service but less appropriate for connections that require quality of service (Murizah & Hafizoah, 2011).

2.3 Bandwidth usage optimization

Manaswi and Venkata (2012) identify three ways of optimizing LAN bandwidth. These include traffic management, caching and compression.

2.3.1 Traffic management

Traffic management is the ability of a network to ensure fairness in a network by guaranteeing that all users in the network receive at least a given amount of bandwidth (Manaswi and Venkata, 2012).Manaswi and Venkata (2012) affirms that in order to ensure that a user in a network does not receive less or more bandwidth, a traffic management solution must have user awareness. In addition the traffic management solution should also be able to control inbound and outbound traffic. Particularly the inbound traffic should be better managed since most of the bottleneck usually occurs here.Queing and scheduling mechanisms provide control over traffic leaving a network but do not address traffic coming into the network. Technologies such as TCP are more advantageous since it provides bidirectional management of traffic with the use of acknowlegdements.Traffic management is essential in optimizing LAN bandwidth, although caching and compression provide additional benefits, without traffic management their effectiveness would be greatly reduced(Murizah & Hafizoah, 2011).

2.3.2 Caching

Caching is used to accelerate the delivery of content as well as optimize the use of LAN bandwidth.Cachig can be implemented in various ways. Browsers a local cache for the recent accessed WebPages' proxy cache which is implemented at the LAN edge and processes requests from many users. The datacenter cache is used to offload servers and help speed the access of data out of the data centre. Proxy caches are the favorites when it comes to bandwidth management (Shittu, Hashim, Anwar & Al-Khateeb, 2008).Shittu et al.(2008) point out that even though caching has the advantage of speeding up retrieval of information from the internet it only suitable for services that do not deal with real time data. Despite conserving internet bandwidth by inspecting logs produced by the proxy server a system administrator is able to establish network usage behavior.Murizah and Hafizoah (2011) believe that when properly implemented caching can have significant impact on bandwidth usage even without implementing other bandwidth management tools. However for caching to be effective it has to be implemented throughout the organization.

2.3.3 Compression

Compression is a bandwidth management technique that is used to reduce the size of a file data to be transmitted through a network. In particular compression can make the network perform as if bandwidth has been increased (Shittu, Hashim, Anwar, & Al-Khateeb, 2008). While there are cases where compression can be effective in optimizing bandwidth usage, (Shittu et al, 2008) believe that there are cases where it is problematic or does not provide any value. For instance in a case where a central site is communicating with a number of remote sites compression does not offer any value in terms of both memory and CPU usage. This is because the more the remote connections the more the CPU utilization in compression which increases latency. In addition, compression offers little value to certain type of traffic such as VOIP traffic. This is because VOIP traffic is already compressed and cannot be compressed any further.Finally,since an effective bandwidth management solution needs to address both the throughput and latency concerns, compression only addresses throughput and increases latency and therefore cannot be used alone.

	Traffic management	caching	compression
Protect mission critical applications	Yes	No	No
Reduce bandwidth	No	Yes	Yes
Optimize bandwidth	Yes	No	No
Core or edge deployment	Core or edge	Edge	Core and edge
Cost of deploying	Variable	High	High

Table 1 Comparing bandwidth optimization techniques. (Manaswi and Venkata, 2012)

2.4 Bandwidth Control and the Hierarchical Network Model.

The internet is based on a Layered architecture where each layer implements a different functionality. The OSI model developed by the international standard organization as a reference model for network layered architecture. The OSI model is made up of seven layers while internet model is made up of four layers. The physical connections e.g. the wires are located at layer 1 while the user is located at the OSI layer7 (Taecheol, Kiyeon & Sangyeun, 2011). Jain and Dovrolis (2008) suggest that traffic management can be applied at any layer.Accesss control is implemented at the internet transport or application layers. For instance the integrated services protocol is at the transport layer. Traffic shaping is implemented at any internet layer for example the TCP protocol at the transport layer, and the differentiated services at the network layer. Practices that utilize deep packet inspection (DPI) utilize multiple layers. Bandwidth management techniques can be implemented at either at the end points (e.g. in a personal computer) or at the transit points (e.g. routers).Most of the network nodes do not contain all the layers. Personal computers implement all the seven layers with the network interface card implementing OSI layers 1 and 2, the operating system (e.g. windows) implements OSI layer 3 and part of layer 4 through 7 and application software's implements layers 4 through 7.The the network router contains layers 1 through 3. Shankaraiah and Venkataram (2010) however suggest that network functionality should be implemented in OSI layers 1 through 3 only if it cannot be implemented efficiently in higher layers.

2.5 Bandwidth management techniques

2.5.1 Queuing and scheduling techniques

Scheduling mechanisms employ different actions on data packets in order to provide different levels of service. These mechanisms are meant to control 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 (Snehalatha, Julia &Rodrigues, 2013).

2.5.1.1 FIFO

In this mechanism the first packet in a queue is the first packet to be served. 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. In case there is no congestion in a FIFO queue, resource allocation in a network is done fast due to the simplicity of the technique. On the other hand FIFO does not provide a means of handling packets which are in different categories. In addition queuing delay increases as congestion increases which affects queued packets .Moreover during network congestion FIFO benefits non connection oriented flows such as UDP over connection oriented flows such as TCP.This is because if a TCP packet is lost, TCP understands that the queue is full and therefore reduces the amount of packets being sent. On the other hand if an UDP packet is lost, UDP continues to send packets normally. This leads to unfair allocation of network resources between UDP and TCP flows.FIFO is effective in situations where the number of packets is less than the capacity of the queue this is because in a case where there are excess packets these packets are discarded(Dhaini,Assi & Shami,2008).

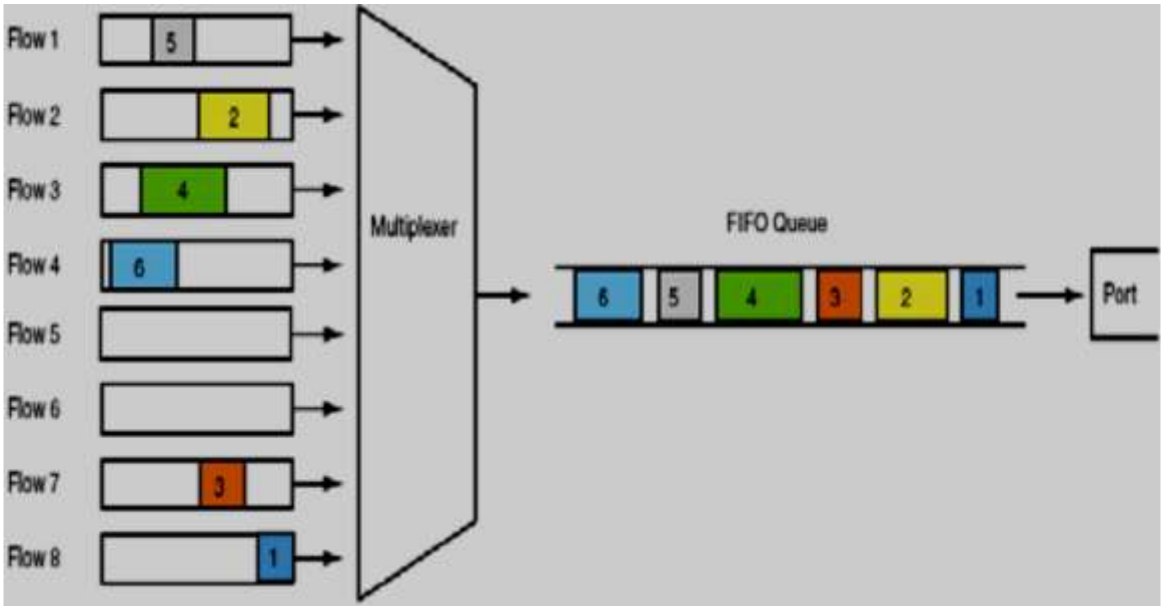

Figure 1.First-In-First-Out (FIFO) queuing **(Snehalatha, Julia &Rodrigues, 2013).**

2.5.1.2 Priority queuing

Priority queuing is one of the most basic forms of scheduling mechanism that allows a fixed number of queues requiring different priorities. This technique provides a differentiated service for different level of queues with the high priority queues being served first. Packets are scheduled in low priority queues if the high priority queues are empty. If the low priority queues are congested packets are dropped. The figure below shows an illustrated example of priority queueing.In this case the flow 3 is classified as high priority while flows 2 and 7 as middle priority flows and the other flows as low priority queues. Packets in the high priority queue are scheduled in a FIFO order. Only when the high priority queue packets are served and the queue is empty, that the remaining queues are served (Okonigene et al, 2011). Jain & Dovrolis (2008) observed that the main advantage of this queuing mechanism is that it is simple and different classes of traffic are handled in different ways. Jain & Dovrolis (2008) also observed that the down fall of this technique is that if the amount of traffic in the high priority queues is too much, the low priority queues would suffer from resource starvation. For this reason, the priority queuing mechanism is not employed in the end to end service guarantees. To avoid starvation, Dhaini, Assi and Shami, 2008 propose that the amount of traffic to the high priority queues should be limited using proper admission control policies. Also priority queuing can be combined with a rate meter such as leaky bucket to ensure that higher priority queues do not monopolize the link.

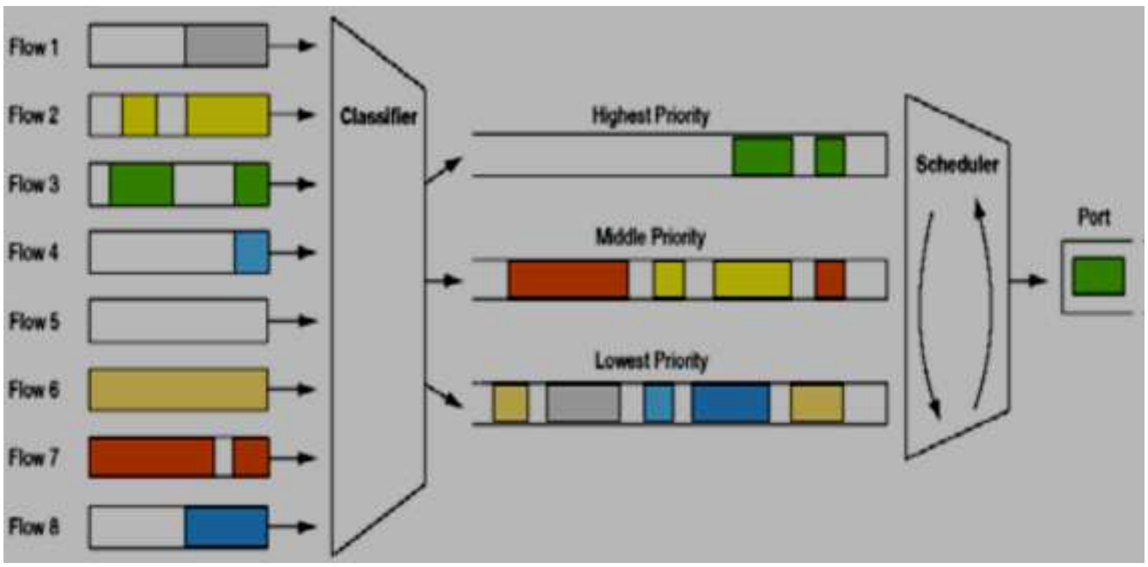

Figure 2. Priority Queuing (PQ) **(Snehalatha, Julia &Rodrigues, 2013).**

2.5.1.3 Fair queuing

In a fair queuing scheme incoming packets are classified into different flows and stored into a queue dedicated to that particular flow. A round robin algorithm is used to allocate network resources to ensure that one source does not consume all the network bandwidth. The main advantage of this scheme is that if a flow is too busty then only its queue is affected and therefore does not affect the overall performance. The downfall of this technique is that it does not take into consideration packet length and therefore if a queue contains bigger packets than other queues then the queue will use more bandwidth and take longer to be served.Fair queuing is useful in sharing bandwidth among many flows but it is not useful for handling different flows of bandwidth requirements (Prasad et al., 2011).

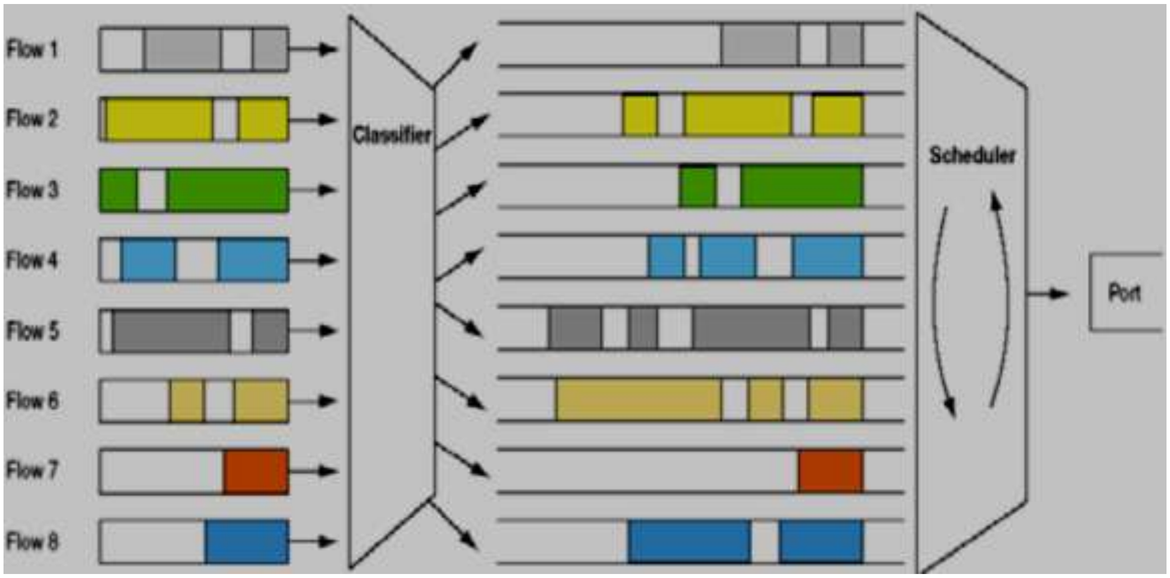

Figure 3. Fair Queuing (FQ) **(Snehalatha, Julia &Rodrigues, 2013).**

2.5.1.4 Weighted fair queuing

The weighted fair queuing algorithm employs a combination of priority queuing and fair queuing algorithims.In this scheme all queues are served so that there is no bandwidth starvation but the weight of a queue determines the amount of service it gets. Certain weights are attached to different queues and packets are stored into the appropriate queue according to their classification. Figure four below illustrates the weighted fair queuing algorithim.At the beginning packets are given to the scheduler .The queue 1 has a weight of 50%,queue 2 and 3 have a weight of 25%.This implies that the finish time for one packet of the same length in the other queue with lower weight. As illustrated in the figure, the first two packets in queue 1 gets the finish time of 30 and 40 respectively; and therefore they are forwarded before the packet in queue 2 with a finish time of 70.The main strength of weighted fair queuing is that it allocates a minimum level of bandwidth to each configured service class .On the negative side weighted fair queuing is not suitable for situations with high volume of traffic requiring many classes of service (Murizah & Hafizoah, 2011).

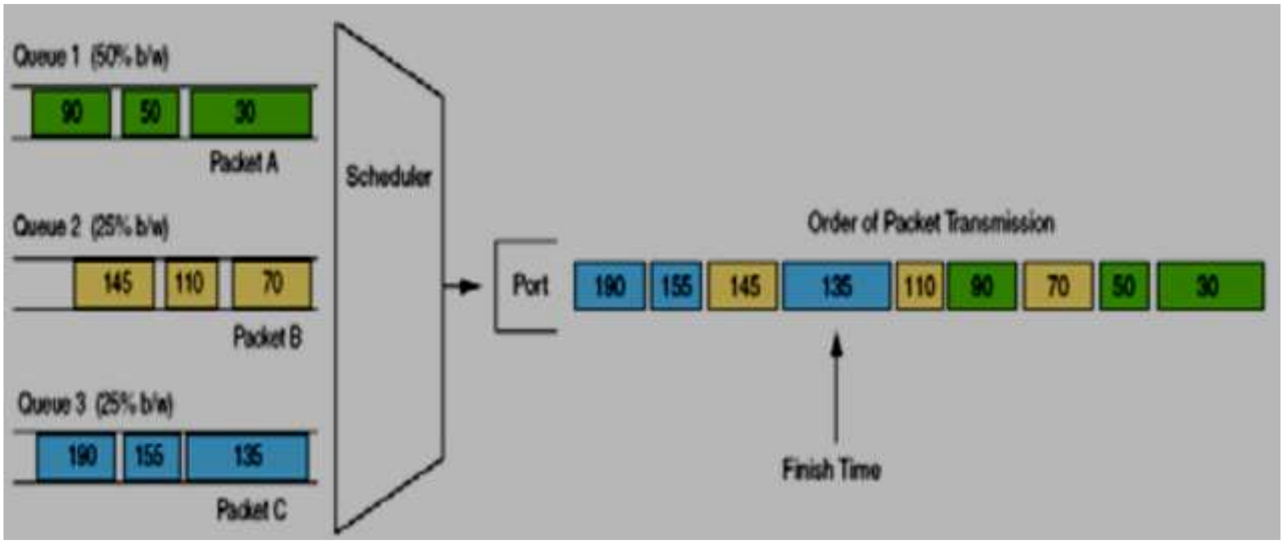

Figure 4. Weighted Fair Queuing (WFQ) (Snehalatha, Julia &Rodrigues, 2013).

2.5.1.5 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 among 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. 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 (Murizah & Hafizoah, 2011).

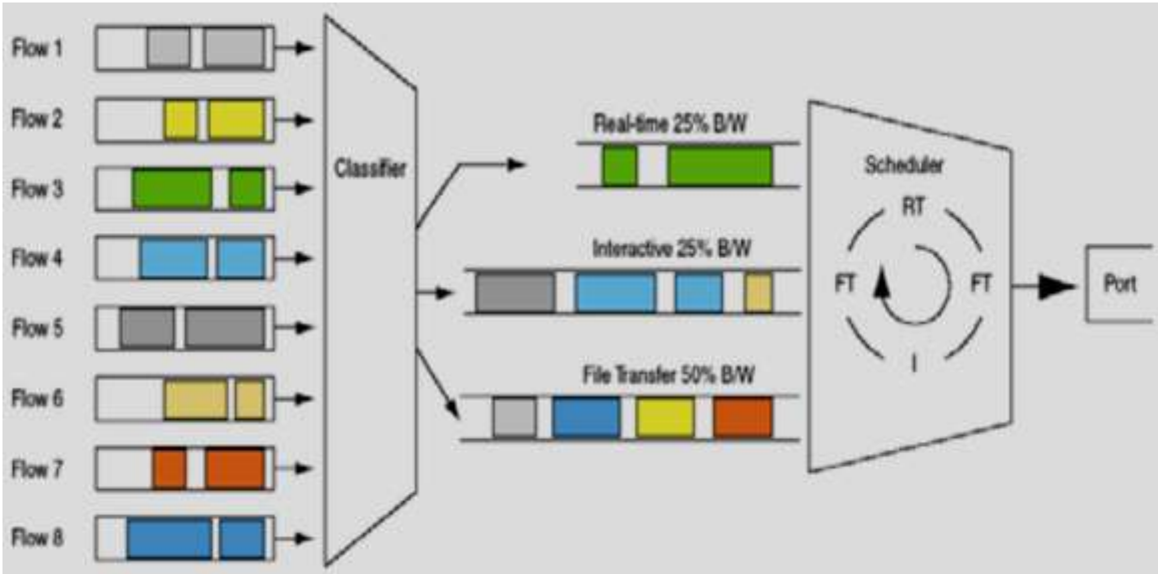

Figure 5 Class-based queuing (CBQ) **(Snehalatha, Julia & Rodrigues, 2013).**

Snehalatha et al (2013) identify the main downfall of packet scheduling as being that it is difficult to implement prioritization. This is because as a general principle of packet scheduling it requires that the average waiting time for all packets does not change under different schedules. This is because giving priority to transmit one packet earlier comes at an expense of making other packets wait longer.Priotizing one packet flow penalizes other packets. This makes fairness an issue when packets schedules are considered. Despite this drawback packet scheduling techniques are easier to implement (Snehalatha, Julia &Rodrigues, 2013).

2.6 Admission control and traffic shaping techniques

This mechanisms first checks whether there are enough resources available to serve new traffic, if the network resources are available, the packets are admitted to flow in the network. This is done to prevent network overload. If admission control is not employed, it is difficult to provide different service classes in an efficient way because it is not possible to prevent a service class from using more than the maximum amount of network resources reserved for that class. In this mechanism packets are classified and the admission filter checks whether there is adequate resources according to that particular service classification. The admission control enforces the use of network resources based on a certain policy. One of the techniques employed in admission control is the capacity based admission control which examines how flows are admitted until capacity is exhausted (first come first admitted) without any additional check. Any new flows are not allowed until there are network resources available. Another admission control mechanism includes one that allows flows to preempt others according to certain priority settings. This method provides the advantage of efficient service as the amount of resources used by low priority traffic is controlled (Shankaraiah & Venkataram, 2010). However Kashihara and Tsurusawa(2010) believe that increasing high priority traffic can affect the performance of lower priority traffic therefore good control algorithms should be employed.RFC 2751 and RFC 2815 describe admission control in a priority queued system. After the traffic has been admitted into the network via admission control techniques, traffic shaping techniques are used to control the volume of traffic entering the network. This ensure that the flow of packets is smoothed based on the configured profile of traffic load on the network. Traffic shaping is implemented using a leaky bucket filter and token bucket techniques (Shankaraiah & Venkataram, 2010).

Kashihara and Tsurusawa (2010) observed that traffic shaping can be done at the end systems or in the network by the switch hardware. At the end of systems can be implemented by the servers using a leaky bucket (single or dual shaper) consisting of a buffer and rate control mechanism, shaper delay and delay variation and the shaper buffer size at the server. The rate controller determines the outgoing data rate which should be consistent with the bandwidth available in the network. Close loop feedback rate control utilizes feedback obtained from the network to control traffic rate. The traffic shaper requires a large buffer to accumulate the incoming busty stream. Traffic shaping controls the data transfer rate. Data transfer rate can be limited to a specific configured rate or derived rate based on the level of congestion. The rate of transfer depends on burst size, mean rate and measurement interval. The mean rate is equivalent to burst size divided by the interval. When traffic shaping is enabled the bit rate of the interface will not exceed the mean rate at any time. This implies that during every interval a maximum burst size can be transmitted. Traffic shaping smoothes traffic by storing traffic above the configured rate in a queue. In a shaping scheme when packets arrives the interface for transmission the following happens; if the queue is empty the arriving packet is processed by the traffic shaper. If possible the traffic shaper sends the packet. Otherwise the packet is placed in the queue. If the queue is not empty, the packet is placed in the queue. When there are packets in the queue, the traffic shaper removes the numbers of packets it can transmit from the queues every time ***t*** interval.

2.6.1 Leaky bucket

In the implementation of leaky bucket algorithm, each host is connected to the network by an interface containing a leaky bucket which is a finite internal queue. When a packet arrives at the queue, the algorithm checks whether the queue is full, if it is full the packets are dropped. This implies if more than one processes within the host try to send a packet when there is already a maximum number of packets queued, the new packets are dropped. Any host in a network is allowed to put one packet per allocated time onto the network. When a packet arrives and the queue is not full, it is appended to the queue otherwise it is discarded. At any time **t** one packet is transmitted unless there are no packets to be transmitted. The algorithm uses a counter which is initialized to ***n***.If the current packet has got a size less than the current value of n, it is transmitted and the counter is decremented by the number of bytes equal to the size of the packet. Additional packets may also be sent as long as the counter is high enough. This mechanism is used to smoothen out excess traffic. Excess chunks of traffic are stored in the bucket and sent at an average rate (Traver & Tarin, Cardona, 2009). According to Traver et al. (2009) the leaky bucket algorithm is most effective in situations where there is a need to enforce a constant transmission rate in a network. This is useful if the purpose for the bandwidth management is to ensure that traffic is at a constant rate. However Kashihara and Tsurusawa (2010) identify this as a weakness since most of the internet applications are bursty in nature and enforcing an average rate would deteriorate network performance.

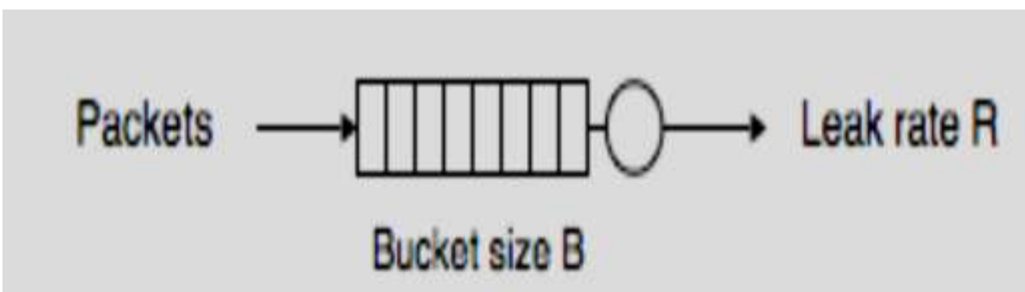

Figure 6 Leaky bucket Algorithms (Traver & Tarin, Cardona, 2009)

2.6.2 Token bucket

This technique controls the traffic by the use of tokens. A token is generated at a rate of one toke every **T** time units, and then these tokens are stored in token pool of finite size **S**.In case the token pool is full, any additional token is discarded. For a packet to be transmitted it must make use of a token from the token pool. If a packet finds the token pool empty the token can either wait for anew token to be generated or it is discarded. The token bucket algorithm saves up tokens during idle times which are used later when there are no tokens in the bucket. This optimizes the speed of the network if N packets meet N tokens. But it can also cause congestion if the traffic gets too busty (Traver & Tarin, Cardona, 2009).

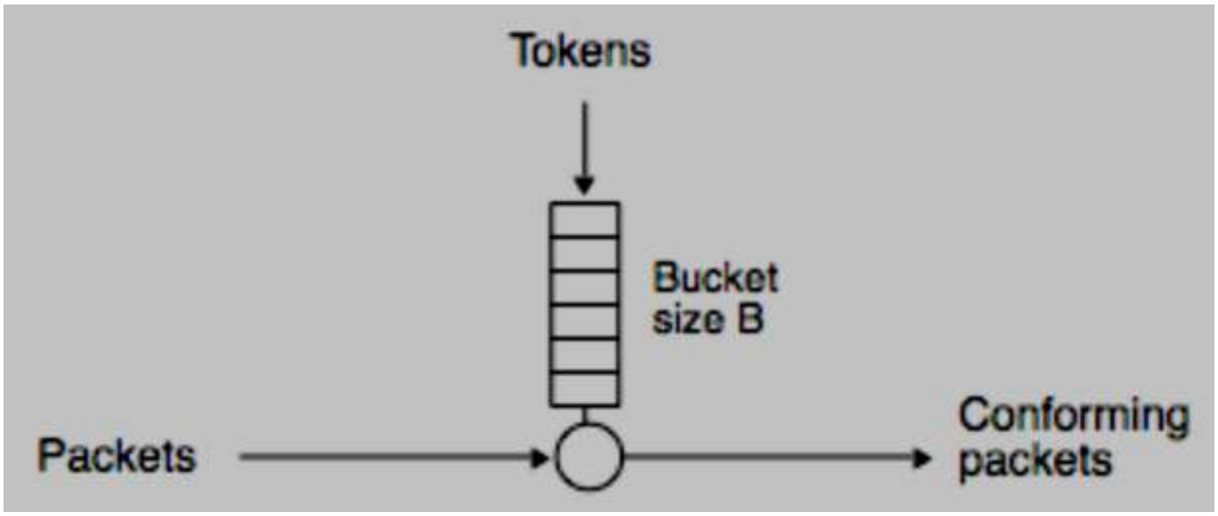

Figure 7 Token Bucket Algorithm (Traver & Tarin, Cardona, 2009).

2.7 Bandwidth Management Implementation Tools

2.7.1 Cisco routers

Cisco systems have an operating system (IOS) that can be configured for bandwidth management tasks. The Cisco IOS supports two kinds of bandwidth management mechanisms-shaping and policing (Cisco, 2013).

2.7.1.1 Cisco shaping methods

2.7.1.1.1 Generic traffic shaping (GTS)

This is the default shaping method found on Cisco routers. It uses token bucket algorithm to smooth outgoing traffic to a particular bit rate.GTS is implemented in a particular interface and uses access control lists to select traffic to shape.GTS can be configure on a frame relay sub interface for dynamic bandwidth allocation. In this particular case GTS uses backward explicit congestion notification or shaping traffic to a specified rate.GTS uses weighted fair queuing (WFQ) for outgoing packets.(Cisco,2013).

2.7.1.1.2 Class based shaping

This shaping method applies GTS on a particular class of traffic. In CBS, GTS utilizes traffic classes which increases flexibility in configuration.CBS supports CBWFQ as its queuing mechanism for outgoing packets. A maximum of 64 classes can be configured in CBS as well as bandwidth assignment for each particular class (Cisco, 2013).Peak and average traffic shaping rates can be configured for each particular interface or class. This implies that bandwidth can be allocated more effectively as it provides more data to be sent if bandwidth is available (Cisco, 2013).

2.7.2 Linux

Linux is an open source operating system that can be configured in a network on a server or client computer for bandwidth management.McMullin (2010**)** points out that since Linux kernel contains the ability to manage and control networking traffic using the tc command and with the correct configurations Linux can be used to implement traffic policing and shaping for bandwidth management. The tc command controls traffic leaving a certain interface through traffic shaping. In addition to control incoming traffic to an interface, the tc command uses a process called ingress policing.tc implements policing by use of a buffer less token filter which implies in a case when packet arrival rate is more than the token bucket configurations packets are dropped. For sequencing of packets, tc supports queuing and scheduling mechanisms such as FIFI, Priority Queuing, Token bucket filter and Schotastic fair queuing. To implement bandwidth sharing in a network tc utilizes the class based queuing and hierarchical token bucket. In addition tc uses the inbuilt u32 classifier or the Linux IP tables firewall package (McMullin, 2010**).**

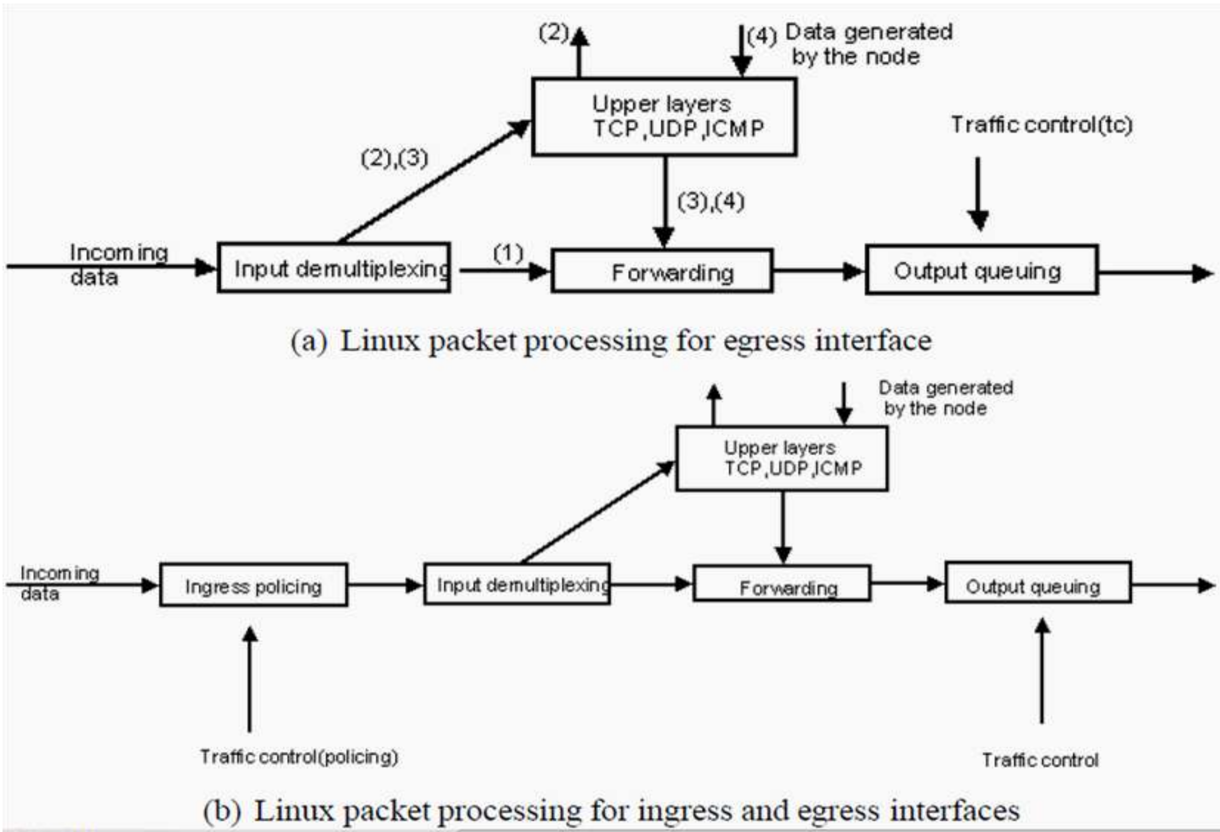

Figure 8: Linux packet processing (McMullin, 2010).

2.7.2.1 Squid Linux

For traffic management squid utilizes proxing and caching features. In addition squid to support bandwidth management squid uses delay pools for bandwidth management by limiting the bandwidth for a particular user or group of users. Squid delay pools use the token bucket algorithm to allocate bandwidth to users connected to the internet. Each configured pool has a max value and a restore value. The max value indicates the maximum size of the token bucket while the restore value is the rate at which tokens are replaced into the bucket. Squid keeps log files of all sites visited which can be used by network administrators to determine bandwidth requirements for a particular user or group of users (Devajit, Majidul & Utpal, 2013).

2.8 State of practice

From the literature reviewed it is evident that there is not a single definitive way of optimizing bandwidth utilization. Kaseridis et al (2010) affirm to this based on the fact that in every single network environment has different needs and resources and this makes the approaches of bandwidth management to vary depending on the target environment. The following are some of the efforts made by organization in various countries in an effort to manage and optimize bandwidth.

2.8.1 Bandwidth management and optimization in the U.K case of Blackburn College

The joint academic network (JANET) is the UK's education and research network that connects UK's universities to each other and to the internet. It is managed by the United Kingdom Education and Research Networking Association (UKERNA).Having a large network with high bandwidth demand and limited funding, in the past JANET has not been able to meet the bandwidth demand for its members which led to poor performance and frequent outages. These made JANET embark on a bandwidth management and optimization strategy. The strategy is divided into two parts, an acceptable use policy and technical measures to enforce the policy. The acceptable use policy aims at preventing illegal internet activities like file sharing, denial of service and spamming which consume a lot of bandwidth if not controlled. The policy gives the UKERNA staff the powers to shut down a JANET member for non compliance with the policy. JANET performs network monitoring by use of a system called Netsight which records information about links state and bandwidth usage. This is done to detect and record abnormal traffic levels on an institutions network that may result to illegal activity. JANET also employs caching for faster DNS queries, reliability and reduction of bandwidth usage by the DNS.In summary, to manage and optimize bandwidth, JANET uses an acceptable use policy, user bandwidth limiting and network monitoring. They also provide services to their members in the areas of monitoring, control and reduction of bandwidth usage (JANET, 2014). Blackburn College is a research institute and a JANET member. Blackburn College connects to JANET for access to the internet and to other universities. To conserve bandwidth, the college implements disciplinary procedures to encourage users to use bandwidth wisely and in moderation. Being a member of JANET, Blackburn College is obliged to comply with the acceptance use policy of JANET. This means that the college has to detect and curb abuse of traffic among its users or risk being shut down by JANET. To optimize bandwidth and also comply with JANET acceptable use policy, Blackburn College is targeting to reduce their usage. The college has established an IT policy that covers their network and internet connection. The college also performs constant monitoring and keeps records of network usage. The monitoring is meant to track down a user responsible for any network abuse. The college employs a proxy server which denies access to specific websites and also includes a proxy cache that reduces bandwidth usage. Inbound and outbound traffic is filtered by the boarder router by use of ACLS on the basis of protocols and port numbers. In Future Blackburn College is looking at improving their filtering both at the gateway router and on the proxy server (Kotti, Hamza & Bouleimen, 2009).

2.8.2 Malawi's Mahatma Campus

Malawi's mahatma campus is an academic and research institution located in Blantyre. The largest institution in the college is the institution of medicine through which other institutions connects to the internet via a VSAT link. To manage and optimize bandwidth the college employs traffic shaping and authentication. Internet traffic shaping is done by use of tc and iptables.A RRDtool is used to graph the results. The authentication for users is implemented by use of a Perl script that establishes the number of users logged in and opens and closes slots in the iptables firewall. In future the college targets to implement an integrated bandwidth management approach. This approach will incorporate control of viruses, establishing of network policies and prevention of infected hosts from using up the internet bandwidth. Content filtering will also be used to establish what material is appropriate for access (Iqbal & Rikli, 2011).

2.8.3 Kenya National Education Network

Kenya national education network (KENET) was established in 1999 with an aim of connecting education institutions and research centre's with a goal of sharing knowledge throughout the country. Members are connected via the main node in Nairobi or via Kenya's telecom backbone. Members can connect to the main node at speeds of 3Mbps for the uplink via a leased line and 3Mbps downlink via VSAT.Members networks speeds range from 64 Kbps to 960 Kbps of bandwidth capacity. This shows that members are limited in terms of available bandwidth .This combined with improperly set up networks due to lack of trained staff has made the available bandwidth unusable for most institutions. To solve the problem, as of 2004, KENET has embarked on a training program on network management, security and monitoring for system administrators from member institutions. To address the problem of bandwidth wastage, KENET established custom servers for each member institutions to address problems at that institution. Access control lists are also established on routes to restrict access to only approved services. The networks in all the member institutions were standardized to one uniform platform of firewalled FreeBSD.KENET has employed technical measures to manage and optimize bandwidth for its members. In future the organization targets at an integrated approach consisting of strict policy measures and technical solutions. Also in conjunction with Aidworld, KENET is developing an open source toolkit to provide affordable and reliable bandwidth management regardless of size of the network or network administrator's experience (Carr & Verner, 2013).

2.9 State of art

Argoa and Movsichoff (2009) identifies differentiated service as a simple and scalable solution for classifying and managing network traffic for providing quality of service in IP networks.Diffentiated service is based is based on the concept of traffic flow classification where each packet is placed into a number of traffic classes rather than separating network traffic based on individual traffic flow. Each traffic is managed differently based on priority attached to it (Argoa & Movsichoff, 2009). According to McMullin (2010), the main advantage of differentiated service is that packet classification and policing can be done at the edge of the network by a gateway which simplifies the core router functionalities. Traffic control is implemented for a variety of functions, at a variety of layers for a variety of functions. The functions should include determining whether traffic priority transmitted and or dropped or the rate at which traffic is transmitted. The concept of differentiated service is based on a combination of traffic flows and related set of flows are treated the same way. Packets are prioritized at the end system, by the service provider or by the gateway. Packets are allocated bandwidth according to the priority attached to them. McMullin (2010) believe that differentiated service being a class of service model can be used to optimize bandwidth by providing quality of service. It separates traffic by user, service requirement and any other criteria. Packets are marked so that they can be treated differently based on their priority. Differentiated service eliminates the need for network devices to process service level agreement about flows. According to Murizah and Hafizoah (2011), a differentiated service model consists of a classifier that selects packets and assigns this packet to a particular class. The classifier selects packets based on one or a combination of source address, destination address, protocol ID source port and destination port. The second element is the meter that measures traffic streams rate for accounting and measurement purposes. The policer is used to enforce policy based on measurements made by the meter. The dropper is used to discard traffic streams that do not conform to its corresponding profile. The shaper delays packets until they conform to some defined traffic profile. The meter, marker, dropper and shaper form the traffic conditioner. Traffic conditioner use policy file to determine how to treat traffic. The traffic conditioner use policy files to determine how to treat traffic. A traffic profile determines whether the packets are conforming or none conforming. Non-conforming traffic may be queued until it is conformed, discarded, remarked or forwarded. Differentiated service provides a simple and clear method of categorizing traffic into different classes (Murizah & Hafizoah, 2011).

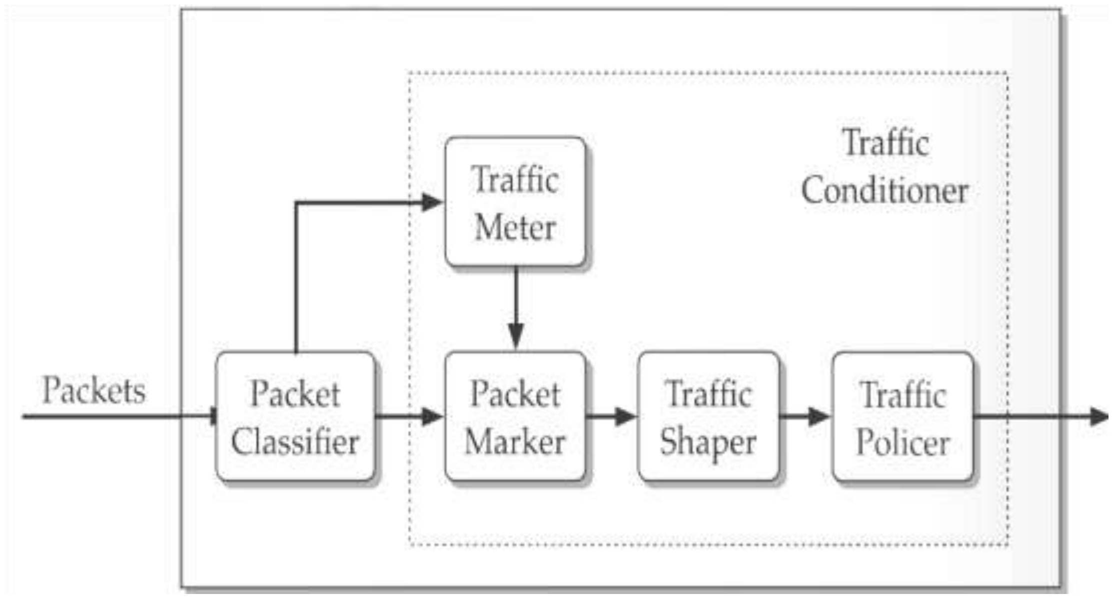

Figure 9 Differentiated service model (Murizah & Hafizoah, 2011).

2.10 Bandwidth management and optimization trends

With bandwidth being a scarce and valuable resource in any network, efficient bandwidth utilization plays an important role in ensuring good network performance in an organization. Kotti, Hamza and Bouleimen (2009) believe that, with constant developments in networks and network technologies, bandwidth managements techniques also have to evolve to remain effective.UBM (unified bandwidth management) is an upcoming trend in bandwidth management proposed by Murizah and Hafizoah in 2011.UBM includes multiple network techniques and control operations that include load balancing, network redundancy, packet/traffic shaping and optimization. UMB also includes network monitoring and reporting on utilization. Many organizations are increasingly using UBM as an integrated approach to solve their bandwidth problems.

As mentioned earlier, Aid world and KENET are in the process of developing an open source toolkit for bandwidth management. The project aims at providing affordable and reliable bandwidth management for use in any institution regardless of the size, link capacity and staff experience (KENET, 2014).Lauren University in the United Kingdom is on a process of developing a BC router. This router is aimed at providing fair bandwidth through equal distribution of bandwidth for every user at the packet level. The per user bandwidth allocation will ensure that users who abuse their bandwidth will not affect others since an increase in their bandwidth consumption will consume their bandwidth share. Other trends in bandwidth management include the integration of bandwidth management tools with interface configuration tools such as IPcop, mOnall and smooth wall which provide traffic shaping and firewalling capabilities and can be implemented on conventional PC hardware. This trend aims at availing good bandwidth management techniques for every internet connection. These new tools and techniques being developed every day will provide network administrators with the capabilities of optimizing performance of already existing networks without the need of major upgrading (Murizah & Hafizoah, 2011).

2.11 Critique of the literature review

The literature reviewed has explored various ways of optimizing bandwidth in a network. The literature is limited to the TCP/IP architecture and how to control bandwidth based on this architecture. In the TCP/IP architecture the literature is again limited to layer three of the architecture. This is because the tools to be used for implementation operate at this layer. The literature has looked at the approaches to bandwidth management which include traffic management, caching and data compression. . In section 2.3 the literature identified traffic management, caching and compression as various approaches to bandwidth optimization. Caching was found to be effective but required that it should be implemented in the whole organization, while compression was found to require CPU utilization especially for remote sites. The literature uncovered that traffic management would be more effective but with integration with caching and compression. Section 2.5 looked at packet scheduling techniques for bandwidth management. These techniques were found to be easier to implement while on the other hand they are ineffective in implementing traffic prioritization. In section 2.6 admission control techniques such as Leakey bucket and token bucket were explored. Leakey bucket was found to be effective in environments where a constant flow rate of traffic is required. However establishing a constant flow rate is not effective since most internet applications are busty in nature. Token bucket algorithm was found to be effective in bandwidth optimization due to its ability to preserve tokens during idle times; however it does experience congestion during working hours. Traffic management and caching are discussed more since they are relevant to the study. Section 2.7 looked at Cisco routers and Linux operating system as examples or real life bandwidth management tools. Both of these approaches were found to be effective but the report proposed Linux since it is open source and therefore easily available, however it requires the system admin to have excellent knowledge in Linux programming. Other tools and operating systems are ignored since they are not relevant to the study. From this we gather that the literature review only support the needs for the study.

2.12 Conclusions

Bandwidth management is an important and emerging challenge for many organizations in the present information age. Absence of proper bandwidth management hinders optimal utilization of internet resource leading to educational institutions being locked out of the global academic community. The literature reviewed has discussed scheduling and traffic shaping mechanisms that have been proposed to provide service guarantees on the Internet. The scheduling mechanisms discussed include FIFO queuing, Priority queuing, weighted fair queuing; class based queuing and fair queuing while shaping mechanisms include leaky bucket and token bucket algorithms. In addition, the chapter has discussed some implementations of bandwidth management mechanisms in routers and open source operating systems. The chapter also briefly discussed Squid, a web cache that can provide a means of reducing the load on Internet links by temporarily storing often-downloaded web pages locally, and subsequently providing the same to clients that request them.Dynamic bandwidth management solution in tertiary institutions will promote optimal usage of internet resources hence maximizing the benefits of internet learning. The literature reviewed has demonstrated a possibility of developing a dynamic bandwidth management system for managing internet bandwidth in tertiary institutions as opposed to the inflexible static bandwidth management mechanisms existing in tertiary institutions.The IT professionals responsible for management of tertiary institutions network system have to monitor users' consumption of bandwidth and dynamically allocate bandwidth according to users' needs to ensure optimal usage. Further more buying of more bandwidth is not sufficient to ensure fast internet access, but there is need to have proper coordination among all stake holders and IT staff on a common internet policy. This policy can be enhanced by implementing monitoring and controlling mechanisms or in other words bandwidth management.

CHAPTER THREE

METHODOLOGY

3.1 Current methods of bandwidth management

3.1.1 Static bandwidth allocation

Static bandwidth allocation involves partitioning a links capacity among the users in the network. This method involves the sharing of a single link among many users using one of the following methods;1) fair bandwidth sharing that involves the sharing of link among many users on equal measures and 2) bandwidth scheduling which assigns a limited amount of bandwidth to existing connections in time slots. The down fall of this approach is that if a certain group of users are not using their share of bandwidth other needy users cannot access it. This leads to bandwidth wastage and congestion during peak hours (Diaconu & Scripcariu, 2010).

3.1.2 Bandwidth reservation

Bandwidth reservation involves an application reserving bandwidth to meet their quality of service. This method is particularly useful for content rich application such as video conferencing and interactive video gaming which require stable predictable quality of service in terms of bandwidth in order to function well. Bandwidth reservation is based on reservation protocol which allows internet or intranet applications to reserve quality of service for their data.RSVP was developed by the internet engineering task force as a standard protocol for bandwidth management and as a component for integrated services in the internet. During data transmission an RSVP enabled application on the receiving side send an RSVP request along the data path to the sending application. At each stage along the route, the QOS is negotiated with network delays. Non-RSVP network devices do not participate in the RSVP negotiation.RSVP is effective in small networks only, but when it comes to internet sized networks, intermediary devices in the network would be overwhelmed by due to the many preservation requests by the millions of data flows. This could lead to memory overflow in the devices and in the end crashing of the devices (Braden et al, 2009).

3.1.3 Preventing bandwidth starvation

Bandwidth can be managed by mechanisms such as guarantees and limits. However priorities provide the most efficient way of dynamically allocating bandwidth. This is because priorities grant privileges to one class over another. Bandwidth priority could be absolute or weighted. With absolute priority, each class of traffic is assigned a priority. The absolute priority operates on the basis of all or nothing principle therefore making it inefficient. This is because when the link is congested, all high priority traffic gets transmitted before any lower priority traffic receives bandwidth. As a result low priority traffic may be starved of bandwidth. In order to prevent bandwidth starvation weighted priority is used. In this case packets are allocated bandwidth based on importance. The weights define the basis upon which traffic competes for available bandwidth. Weighted priority enables network managers to provide the only means prioritizing traffic and preventing starvation (Yongtao et al, 2010).

3.2 Evaluation of current methods

Static bandwidth allocation discussed above does not provide the flexibility of one class to use the other classes bandwidth in case there is some available. This leads to bandwidth wastage. A good bandwidth management technique should provide for bandwidth sharing so as to optimize bandwidth and reduce wastage (Diaconu & Scripcariu, 2010). Bandwidth reservation has also been discussed as bandwidth management technique that reserves bandwidth for RSVP enabled applications. In a case where these applications do not use do not make use other reserves and other applications are not able to access it, this leads to wastage of reserved bandwidth. To be efficient, bandwidth reservation traffic should provide the flexibility of bandwidth borrowing (Braden et al, 2009).Weighted priority may be used to prevent bandwidth starvation. But as long as bandwidth is assigned using priorities, the low priority classes are bound to suffer from partial starvation. To prevent this starvation, every class should be assigned a guaranteed rate for which the class can access at any particular time irrespective of the nature of the link. This will ensure that at any particular moment all the classes are assured of a minimum amount of bandwidth. To be able to optimize the usage, borrowing should be configured for class based on the priority. This implies that high priority classes are allowed to borrow first ensuring that they get special treatment as well as prevent total starvation of the low priority classes (Yongtao et al, 2010).

3.3 Definition of the tool to be adopted

3.3.1 Bandwidth borrowing using HTB

Hierarchical token bucket is a class based scheduler that supports hierarchical link sharing, traffic prioritization and bandwidth borrowing between classes. Hierarchical token bucket is included in the Linux operating system kernel for traffic control. Hierarchical token bucket is based on the token bucket theory where token bucket filters are placed in a tree like structure to form the bandwidth sharing hierarchy. The hierarchy is made up of the root class, several parent classes and child classes. The root class is the top most token bucket filter with the other token bucket filters placed under it forming the parent classes and the leaf classes.

Parent classes are configured for with parameters on how bandwidth is to be shared among it child classes (Diaconu & Scripcariu,2010).Each class in Hierarchical token bucket is configured a guaranteed rate (GR), a ceiling rate(CR) and priority rate(P).An actual rate R can be derived as follows for a class a Ra=Min (CRa, GRa+Pa)………………. 3.1(Diaconu & Scripcariu,2010)

From equation 3.1 we observe that a class can have actual rate greater or equal to the guaranteed rate which also should be greater or equal to the ceiling rate depending on how much bandwidth is to be borrowed from other classes. The bandwidth to be borrowed depends on how much the network is busy as well as the associated priority of the class.

According to Ravindran, Rabby and Liu (2009), Hierarchical token bucket is based on three classes; the root, parent and leaf classes. Traffic from upper layers is classified using filters before arriving at the leaf classes, this is important so that different of traffic with different priorities can be given different treatment. In traffic classification process, traffic can be filtered based on ports, kinds of services offered, IP addresses or network addresses. After the traffic is classified it is then queued and sent to the destination. In a case where a class requires more bandwidth, this traffic is shaped before forwarding. Hierarchical token bucket uses tokens and token buckets in traffic classification, scheduling and shaping. To increase the through put Hierarchical token bucket, generates tokens at necessary intervals and dequeues packets from the bucket only if tokens are available. The main strength of a hierarchical token bucket traffic shaper is that of bandwidth borrowing. When a class reaches guaranteed rate GR, it borrows tokens from its parent class. When a class has reached ceiling rate CR, it queues packets until new tokens are available. Hierarchical token bucket is included in Linux kernel 2.4.10 and above (Murizah & Hafizoah 2011).

3.4 Proposed method

To achieve the objective of this study, which is to develop a bandwidth manager prototype, the study adopted an evolutionary prototyping methodology. Taecheol et al (2011) describes evolutionary prototyping as a technique that acknowledges that we do not understand all the requirements and builds only those that are well understood. This methodology was chosen because it provides for the development of a system in an environment where the system requirements may change overtime. This type of prototyping starts with the collection of the requirements. After the collection of the requirements, a prototype is designed to fulfill these requirements. Then the prototype is designed, implemented, tested and then used. Ensuing steps involve refining the requirements, re-designing, re-implementation and re-testing .The prototype will then be designed, implemented and evaluated (Carr & Verner, 2013). It has been found that evolutionary prototyping is effective in the analysis and design of network management systems for example that of bandwidth management. This is because evolutionary prototyping provides for the user to continuously interact with the system which in turn helps in refining the requirements. In the case of bandwidth management prototype for efficient utilization of internet bandwidth, the prototype would be deployed in the network. The prototype would then be tested for efficient bandwidth management, based on the users feedback, the prototype would be redesigned or implemented as a final product (Peter & Babatunde, 2012).For the purposes of testing the prototype test bed will be implemented emulating Meru Technical Training Institute network conditions. A case study of the Meru Technical Training Institute was done to establish the requirements of the prototype. Case study was used because it enables a researcher to closely examine requirements within a specific context (Yin, 2003).

3.5 Proposed system

In this report a dynamic bandwidth manager prototype is proposed to solve bandwidth management issues in tertiary institutions. The prototype a classifier, bandwidth provisioner and bandwidth borrower. The bandwidth provisioner includes a bandwidth meter which determines if the packet is larger than the allocated bandwidth size, if it is larger than the allocated size the bandwidth borrower is activated otherwise the packets are forwarded without any delays. In case there is need for borrowing ,the bandwidth borrower will check if there is unused bandwidth in the neighboring class in order to borrow, if none is available, the packets are further delayed awaiting for bandwidth to be available otherwise it allocates the unused bandwidth to the borrowing class and packets are forwarded. Traffic was grouped into classes to enable bandwidth sharing. The network was configured with four classes that is the root class 1:0, the staff class 1:10, and the labs class 1:11 and the hostel class 1:12.The root class is configured with 1250kbps of bandwidth. The staff class is configured with a guaranteed bandwidth of 500Kbps and a ceiling of 1000Kbps. The labs class was configured with a guaranteed bandwidth of 500 Kbps and a ceiling of 1000 Kbps while the hostel class is configured with a guaranteed bandwidth of 250Kbps and a ceiling of 250Kbps.The staff, labs and hostel class were configured to borrow 500Kbps, 500 kbps and 0kbps respectively. Each class will borrow bandwidth from the neighbor classes if there is any unused. Traffic was assigned to the classes based on IP addresses. Traffic originating or destined to 172.20.21.101, 172.20.21.102 and 172.20.21.103 was assigned to classes 1:10, 1:11 and 1:12 respectively. The tc command was used to configure bandwidth allocations, classifications and priority. The system is expected to improve browsing experience in the tertiary institutions since each class of users is guaranteed a particular portion of bandwidth at any time. By providing bandwidth guarantee for each class, in a case where there is congestion in one class the other classes are not affected unless there is unused bandwidth from which the needy class will borrow. This method ensures optimal usage by availing unused bandwidth to the needy users. However excess packets will suffer from delays as a result of bandwidth borrowing.

3.6 Tools employed

3.6.1 Tele traffic tapper

Tele traffic tapper (ttt) is a network monitoring tool capable of providing real time graphical and remote traffic monitoring.ttt is able to display two separate graphs on the behavior of the traffic in two windows. On one window it displays protocol information and on the other window it displays particular hosts bandwidth consumption.ttt displays traffic behavior for the last 60 seconds with the graphs being updated every second by default (Shankaraiah & Venkataram, 2010).In this study ttt was used to graph the utilization of bandwidth by the hosts in the test network. It was also used to demonstrate classification and bandwidth borrowing.

3.6.2 Traffic control (Tc)

Tc is a program that is used to manage and control traffic.tc is part of iproute2 package that is used control TCP/IP networking within the Linux systems. The traffic control command is used for traffic classification and manipulation among other networking functions. Traffic control uses filters to classify packets using either IP addresses or port numbers. In this documentation the u32 filter is used to classify packets based on IP addresses (Kelly, 2012).

3.6.3 Squid proxy

Squid is a caching proxy that has support for HTTP, HTPPS and FTP.Squid was used to implement bandwidth optimization by use of caching where frequently used pages are reused. The proxy was also used to define the IP addresses visible to it by use of access control lists.(Shankaraiah & Venkataram, 2010).

3.6.4 Interview

The study of the Meru Technical Training network targeted to establish the requirements to consider during prototype development. In order to establish the status of internet connectivity, an interview was used. The interview was administered on the systems administrator. This individual was sampled since he was perceived to understand computer networks (Kothari, 2004).

3.6.5 FileZilla

This is free software used for uploading and downloading information from or to remote hosts (Ravindran, Rabby & Liu, 2009). In the study FileZilla uploads and downloads were used to emulate internet traffic.

3.7 Conclusion

This chapter has looked at the existing methods of bandwidth management. It has also evaluated these methods on their effectiveness to optimize bandwidth. In this chapter a dynamic bandwidth management prototype is proposed. The prototype is to be developed using evolutionary prototyping methodology. To get the requirements for the prototype, a study of the Meru Technical Training Institute Network was done. The chapter has also looked at the tools to be used and how the prototype will be tested.

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CHAPTER FOUR

DESIGN AND IMPLEMENTATION

4.1 Prototype design

The prototype design was based on the token bucket algorithm. Recall that a token is permission to transmit one bit of data (Murizah & Kassim, 2011). Therefore each class bandwidth allocation was presumed to be a token bucket from which a neighboring class can borrow tokens or bandwidth in case of a shortage. The prototype was deployed in a gateway server running Linux and squid proxy. The design consisted of a classifier, a bandwidth provisioner and a bandwidth borrower. The bandwidth provisioner and the borrower rely on the classifier to make decisions on how to treat the packets.

4.1.1 Prototype design model

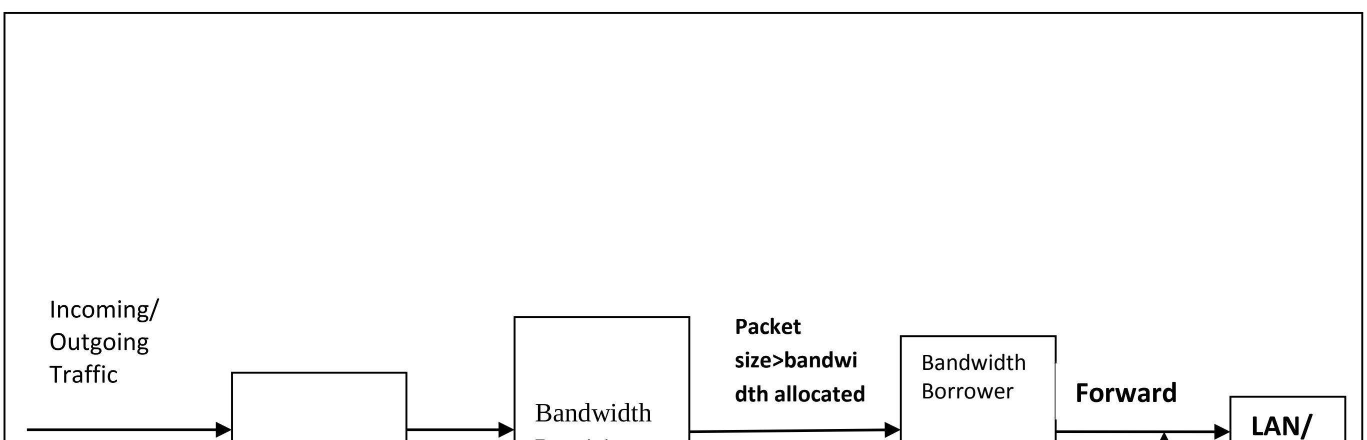

Figure 10 Prototype design

4.2.1 System flow chart

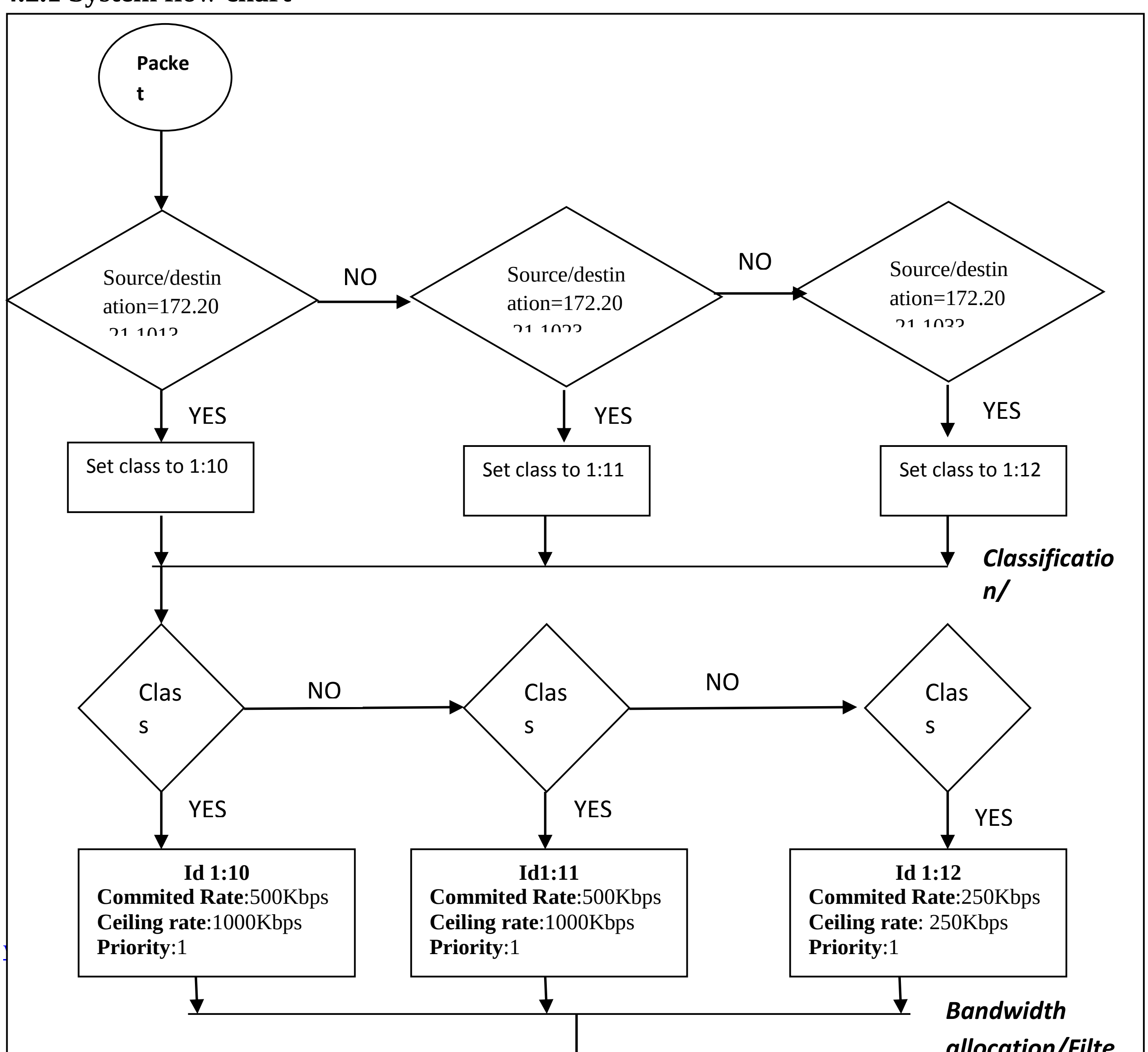

Figure 11 Flow Chart

4.1.3 The classifier design

The following configurations were made on the firewall to classify traffic

```
*mangle
   : POSTROUTING ACCEPTS [0:0]
   -A POSTROUTING -s 172.20.21.101 -o eth0 -j CLASSIFY --set-class 0001:0010
   -A POSTROUTING -s 172.20.21.102 -o eth0 -j CLASSIFY --set-class 0001:0011
   -A POSTROUTING -s 172.20.21.103 -o eth0 -j CLASSIFY --set-class 0001:0012
   -A POSTROUTING -d 172.20.21.101 -o eth0 -j CLASSIFY --set-class 0001:0010
   -A POSTROUTING -d 172.20.21.102 -o eth0 -j CLASSIFY --set-class 0001:0011
   -A POSTROUTING -d 172.20.21.103 -o eth0 -j CLASSIFY --set-class 0001:0012
  COMMIT
```

The **s** and **d** were used to indicate traffics originating from and destined to the respective IP addresses. Traffic originating or destined to IP address 172.20.21.101 was put in class 1.11, Traffic originating or destined to IP address 172.20.21.102 was put in class 1.12 and finally

We used the tc command and tc filters to classify traffic. The tc filter U32 was then used to filter the traffic and assign them to classes based on their IP address. The code below was used to filter traffic and match the IP addresses to their appropriate classes.

Filtering downloads

```
#sudo tc filter add dev eth0 protocol ip parent 1:0 prio 1 u32 match ip dst 172.20.21.101 flowid 1:10
#sudo tc filter add dev eth0 protocol ip parent 1:0 prio 1 u32 match ip dst 172.20.21.102 flowid 1:11
#sudo tc filter add dev eth0 protocol ip parent 1:0 prio 1 u32 match ip dst 172.20.21.103 flowid 1:12
```

Filtering uploads

```
#sudo tc filter add dev eth1protocol ip parent 1:0 prio 1 u32 match ip src 172.20.21.101 flowid 1:10
#sudo tc filter add dev eth1 protocol ip parent 1:0 prio 1 u32 match ip src 172.20.21.102 flowid 1:11
#sudo tc filter add dev eth1 protocol ip parent 1:0 prio 1 u32 match ip src 172.20.21.103 flowid 2:12
```

The dst key word was used to filter download traffic while the src key word was used to filter upload traffic. Upload and download from the same source and destination host were put in different classes and assigned to interfaces eth1 and eth2 respectively. This was done to achieve flexibility in bandwidth allocation and graphing.

4.1.4 Bandwidth Provisioner design

The bandwidth provisioner was designed to allocate bandwidth to each class by the use of the rate and ceiling key word. The rate value represents the guaranteed bandwidth to a class at any particular time while the ceiling indicated the maximum amount of bandwidth that can be achieved by a class at any particular time.

The following code was used to allocate bandwidth.

```
1.#sudo tc class add dev eth1  parent 2:0 classid 2:1 htb rate 1250 kbps ceil 1250kbps
2.# sudo tc class add dev eth1  parent 2:1 classid 2:10 htb rate 500kbps ceil 1000kbps
3.# sudo tc class add dev eth1  parent 2:1 classid 2:11 htb rate 500kbps ceil 1000kbps
4.# sudo tc class add dev eth1  parent 2:1 classid 2:12 htb rate 250kbps ceil 250 kbps.
```

Line one was used to allocate 1250kbps of bandwidth to the parent class 1:1.This represents the total capacity of the link. From the parent class, Line two was used to allocate a guaranteed rate of 500kbps of bandwidth to class 1:10.Lines three and four were used to assign a guaranteed rate of 500kbps and 500 kbps to classes 1:11 and 1:12 respectively. Irrespective of the nature of the link, the guaranteed bandwidth is always available for the assigned class.

4.1.5 Bandwidth borrower design

To implement bandwidth borrowing the ceiling keyword was used to indicate the burst rate that a class can achieve at any particular time. The difference between the ceil and the rate indicates how much bandwidth a particular class can borrow. Bandwidth borrowing is only activated when a class packets exceeds the committed rate.

The following lines of code illustrate how bandwidth borrowing was implemented.

```
1.# sudo tc class add dev eth0  parent 1:0 classid 1:1 htb rate 1250kbps ceil 1250kbps
2.# sudo tc class add dev eth0 parent 1:1 classid 1:10 htb rate 500kbps ceil 500kbps
3.# sudo tc class add dev eth0  parent 1:1 classid 1:11 htb rate 500kbps ceil 500kbps
4.# sudo tc class add dev eth0  parent 1:1 classid 1:12 htb rate 250kbps ceil 250kbps.
```

The ceiling key word was used to configure the maximum amount of bandwidth that can be achieved by a particular class. From the code above, line one was used to configure the parent class 1:1 with a maximum bandwidth capacity of 1250kbps.This means that at any particular time irrespective of the nature of the link, this class cannot use more than the ceiling. Classes 1:10, 1:11 and 1:12 were allocated a ceiling rate of 1000Kbps, 1000Kbps and 250Kpbs respectively. This means that these classes are able to borrow bandwidth equivalent to their ceiling rates.

4.2 Implementation

The prototype for bandwidth management was implemented using the traffic control command available in the Linux kernel. With traffic control we were able to implement classification and bandwidth borrowing. However U32 filters were used as classifiers. In order to allocate bandwidth efficiently IP based classification was used. The dst and src keywords were used to separate uplink and downlink flows. When class packets exceed the committed rate it is able to borrow unused bandwidth from the neighboring classes. The amount of bandwidth borrowed depends on the ceiling value, the higher the value the more bandwidth can be borrowed. To distribute bandwidth among the classes, Hierarchical token bucket was used. A policy file was created to provide parameters for bandwidth allocation and distribution. The policy file contained entries of class names and their corresponding bandwidth values. To optimize consumption of bandwidth on relevant activities, social websites were blocked during working hours by the use of squid proxy.

4.2.1 Implementation model

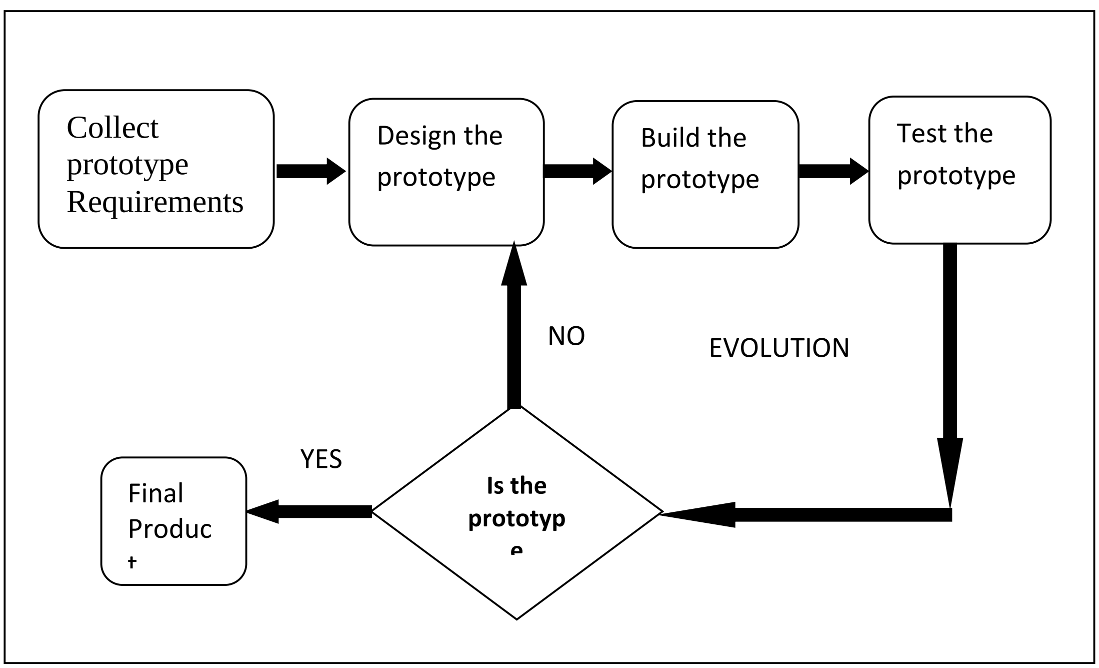

Figure 12 Implementation Model.

4.2.2 Design and Implementation Issues

During the design and implementation of the prototype the following challenges were encountered. The first being that Traffic control command can only manage outgoing traffic from an interface of a device, incoming packets cannot be affected by the Traffic control command (Arcia et al, 2009). For this reason to successfully manage uploads and downloads, we had to configure interface eth0 for upload and interface eth1 for download. Interface eth0 was configured to manage traffic from test computers and interface eth1 was configured to manage traffic to the test computers. This ensured that both the download and uploads were shaped. The U32 classifier was used to classify packets. The U32 has a fault in that it produces duplicate value entries when same priority values are used for different classes (Largoa &

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Movsichoff, 2009). To avert this, the implementation used the same priority value of 1 for all the classes.

4.3 Testing

The prototype was evaluated for bandwidth borrowing, allocation and classification. The test bed comprised of one switch, a laptop that acted as a gateway which also run the prototype and three computers that acted as traffic sources. Traffic was generated by downloading and uploading big files using FileZilla in the three computers and the results graphed using tele traffic tapper.

4.3.1 Test model

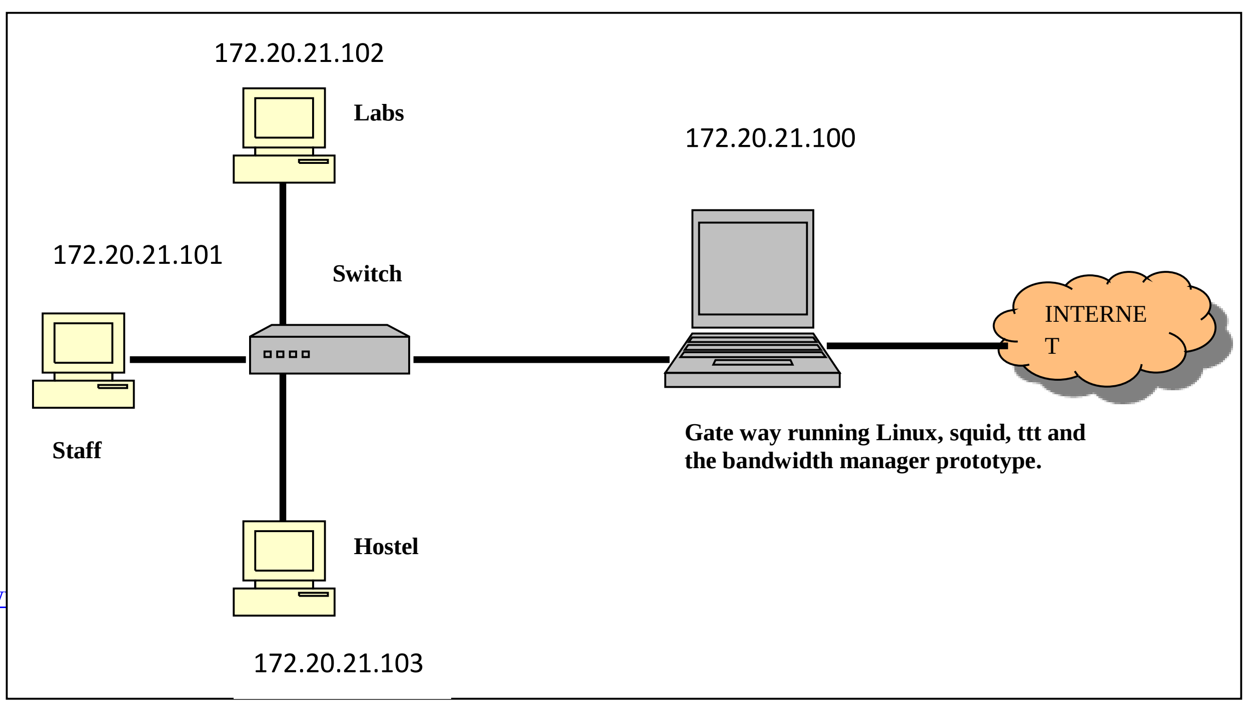


Figure 13 prototype test bed topology.

CHAPTER FIVE

TESTING

5.0 Introduction

In this chapter we present the findings of the prototype testing. In section 5.1, we present the findings on Meru Technical Training Institute network study which includes the status of internet access, bandwidth management strategies employed and challenges to bandwidth management in the institution. In section 5.2 we present the findings on prototype testing. This includes the test on bandwidth classification functionality, the test on bandwidth allocation functionality and the test on interclass bandwidth borrowing.

5.1 The study of Meru Technical Training Institute

The study of Meru Technical Training Institute network was done to establish the status of internet access, bandwidth management strategies and challenges to bandwidth management. The study was done to collect requirements for the prototype design.

5.1.1 Status of internet access

Table 2 internet connectivity status

Network service	**Connectivity**
Number of networked computers	150

Number of users	2050
Size of bandwidth	2Mbps
Type of internet link	Copper wire

The staff the ratio of computers to that of the user is was found to be 1:1 while that for the student to computers is 20:1.The bandwidth capacity was found to be 2Mbps for both uplink and downlink.

5.1.2 Bandwidth Management strategies

Table 3 Bandwidth Management Strategies

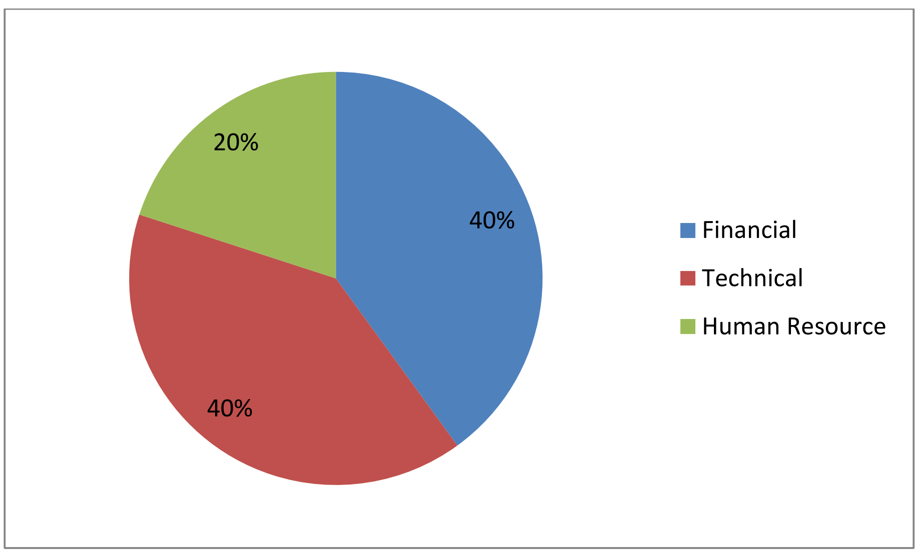
Strategy	Status
Web caching	Present

Network monitoring	Present
Antivirus	present
ICT policy	Not present
Acceptable user policy	Not present
Bandwidth management policy	Not present
ICT strategic plan	Not present

The data collected revealed that the institution implements web caching, network monitoring and antivirus programs for traffic management.

5.1.3 Challenges to bandwidth management

Figure 13 bandwidth management challenges



The challenges to bandwidth management were reported to be 40% technical, 40% financial and 20 % human resource. Technical challenges include uncontrollable user downloads and varying bandwidth requirements, the financial challenges include high cost of bandwidth management and high cost of bandwidth management software. The human resource challenge includes lack of skills by the system administrator on how to manage bandwidth.

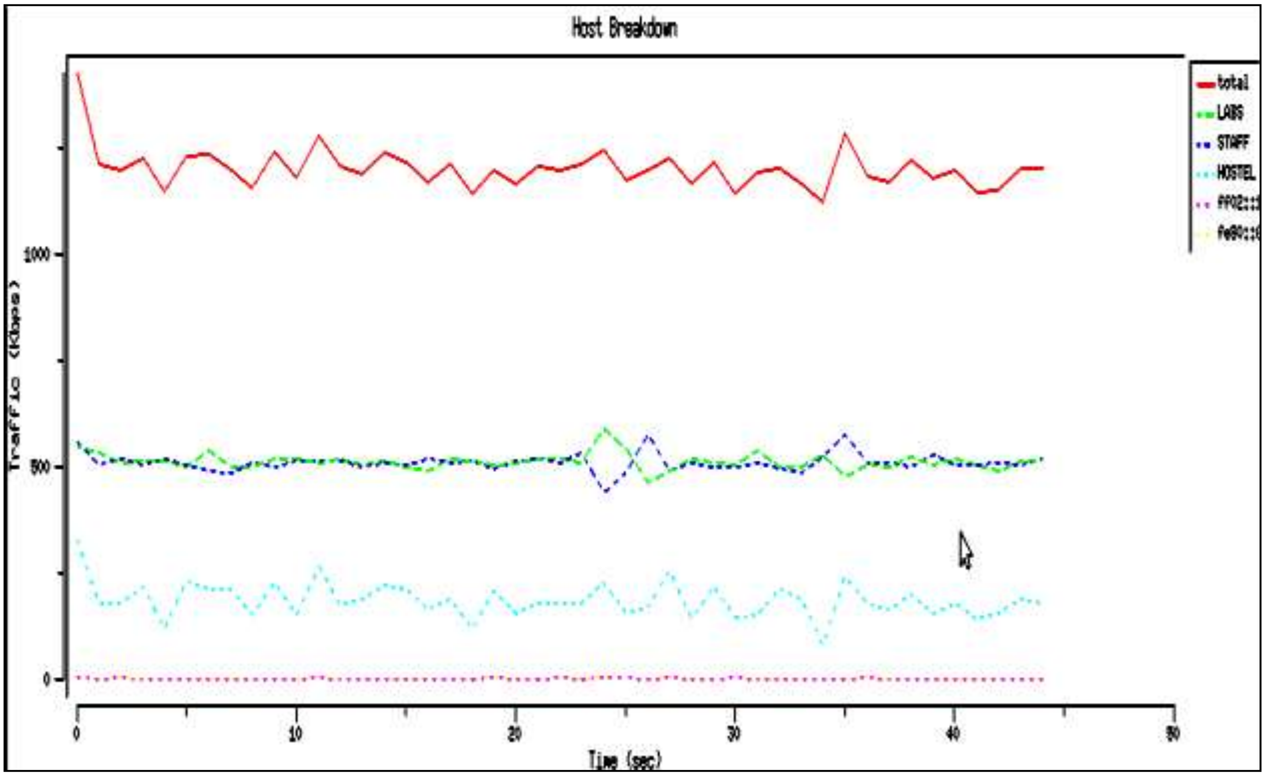
5.2 Prototype testing

In this section we present findings of the bandwidth manager prototype testing. The tests were designed to evaluate the prototype for packets classification according to IP addresses; accuracy in bandwidth allocation and the ability for inter class borrowing.

5.2.1 Testing for classification functionality

The classifier was designed to separate traffic destined and originating from the staff, labs and hostel networks. To classify traffic we used source and destination address. Then we used the hierarchical token bucket to allocate bandwidth. In testing for the classification functionality we evaluated the matching of the IP addresses to the classes. If bandwidth allocated to a certain class is associated to a particular host, classification is deemed to have been done. We used the firewall to configure the prototype for this purpose. The purpose for the configuration was to match traffic originating or destined to various machines to the assigned classes. Then downloads were started from IP addresses 172.20.21.101, 172.20.21.102 belonging to hosts staff and labs respectively. Uploads were started from IP address 172.20.21.103 belonging to host hostel.IP address 172.20.21.101 was assigned to class 1:10 while IP addresses 172.20.21.102 and 172.20.21.103 were assigned to classes 1:11 and 1:12 respectively. Classes 1:10 and 1:11 were assigned a committed rate of 500 kbps while class 1:13 was assigned a committed rate of 250 kbps.

Figure 15 Evaluation for classification functionality



As shown in the figure 14 all the hosts could use the committed bandwidth allocated to their respective classes, proving that the prototype could match IP addresses to their respective classes.

5.2.2 Testing for bandwidth allocation accuracy.

Testing for bandwidth allocation accuracy was done to establish if bandwidth could be accurately allocated for both uploads and downloads. To test for bandwidth allocation, we set up the experiment as follows:

i. We created three classes 1:10, 1:11 and 1:12 with class 1:1 being the parent class

ii. Parent class 1:1 was assigned a committed rate of 1250 Kbps.

iii. Classes 1:10, 1:11 and 1:12 were matched to hosts staff, lab and hostel respectively via their IP addresses.

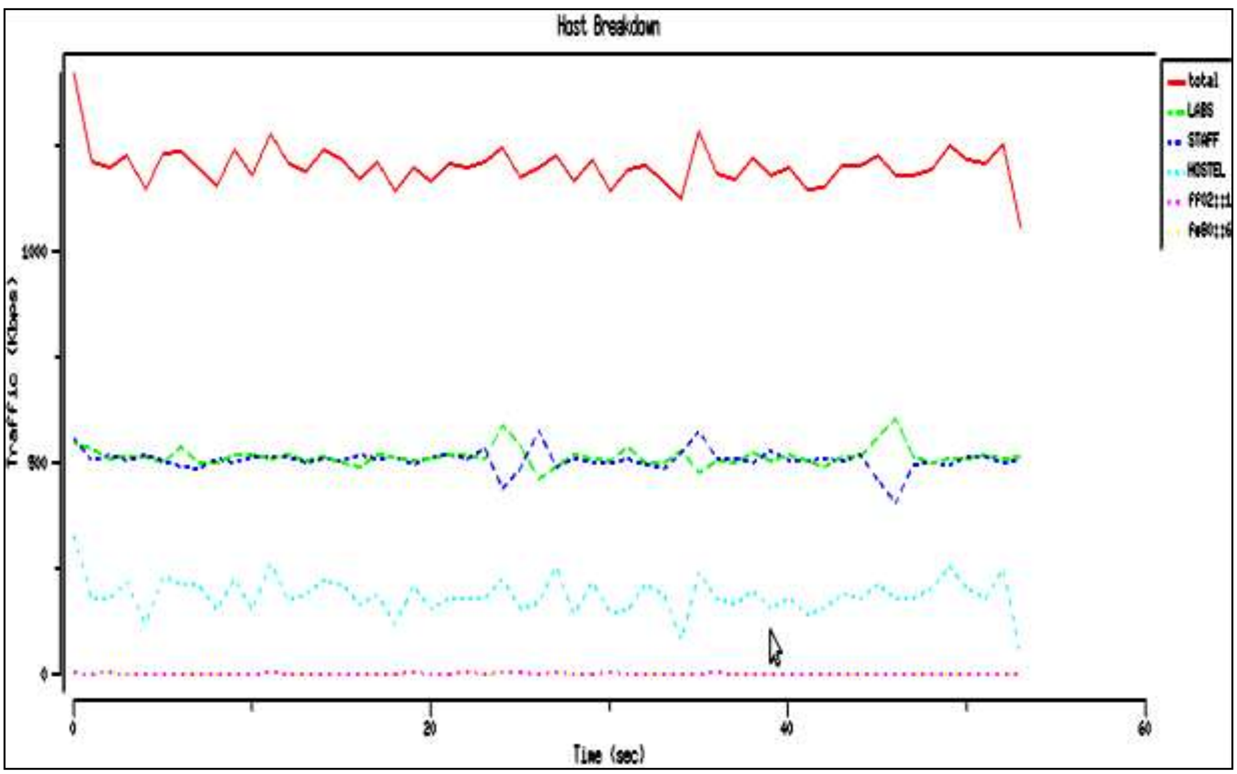
iv. The rate for staff (belonging to class 1:10), lab(belonging to class 1:11) and hostel(belonging to class 1:12) were set as 500kbps, 500kbps and 250 kbps respectively.

v. Next downloads were started from the staff and lab hosts using filezilla.

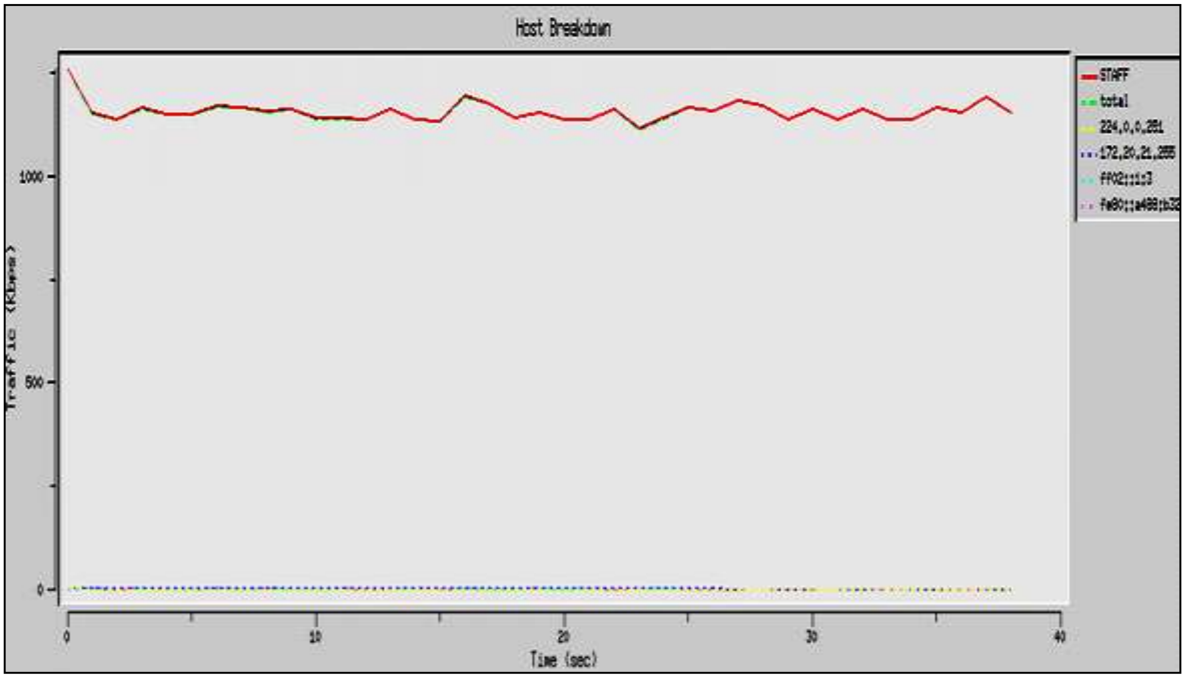
vi. Then we started uploads from hostel host using filezilla.

The figure below shows the results for bandwidth allocation.

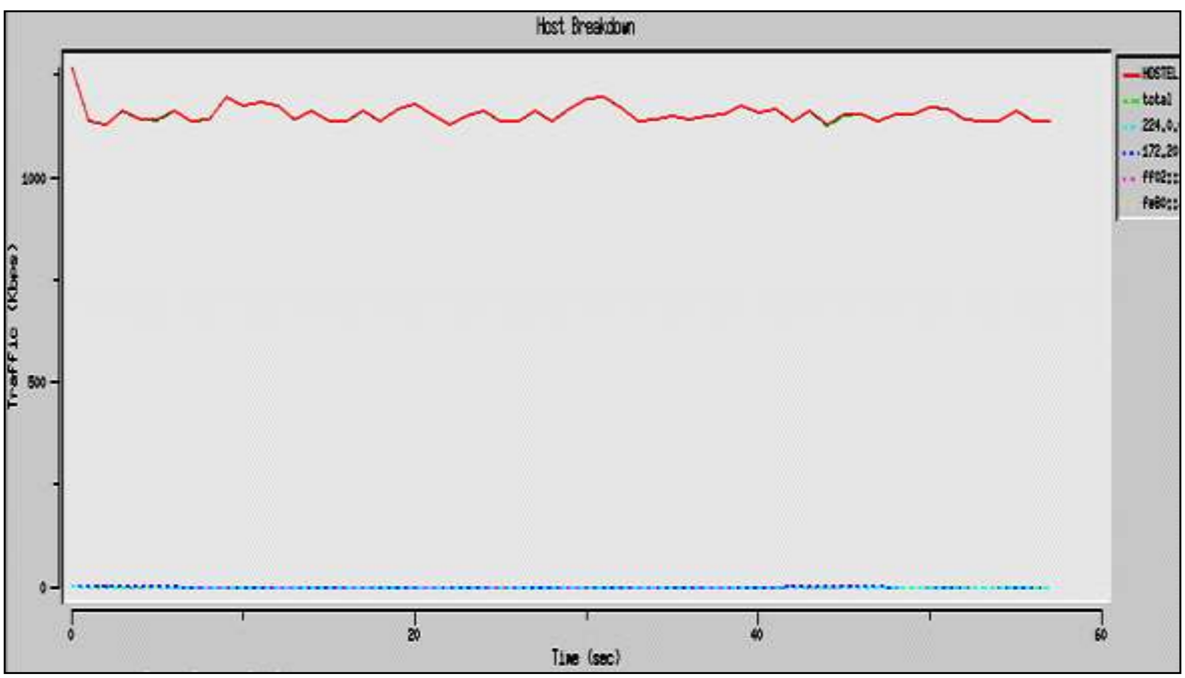
Figure 16 Evaluation for bandwidth allocation



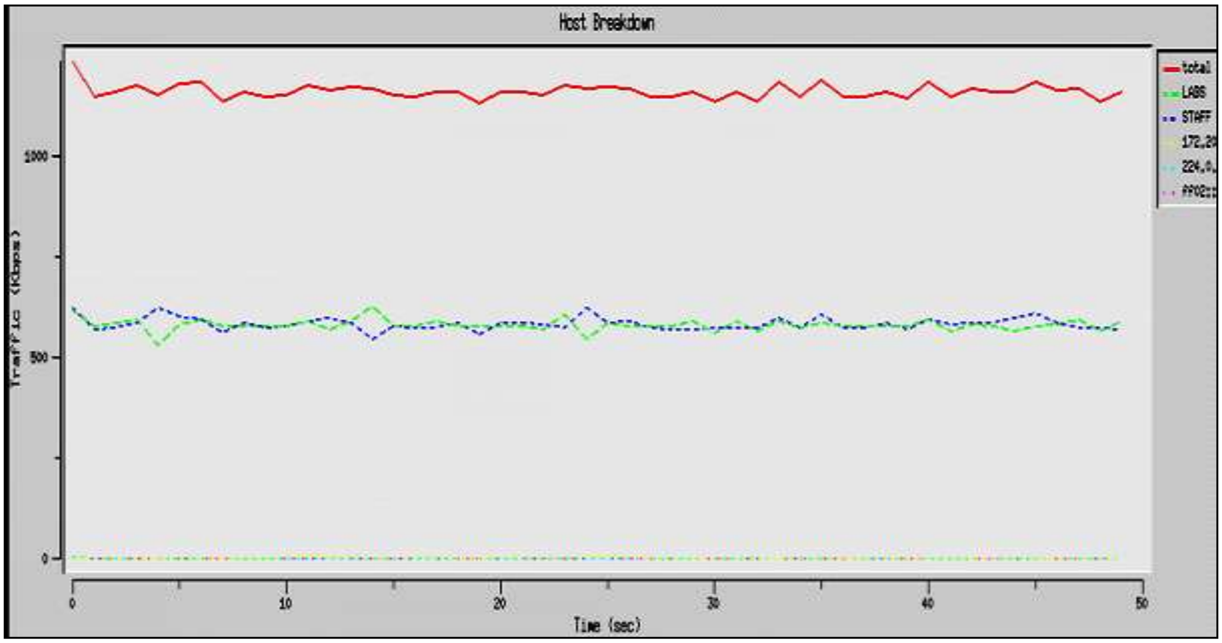
From figure 15 we notice staff and labs hostel could only utilize their share of bandwidth allocation which is 500kbps while the hostel class could only utilize 250kbps.



a) Total utilization of bandwidth by the STAFF class rate=1250 Kbps



b) Total utilization of bandwidth by the HOSTEL class rate=1250 Kbps



c) Total utilization of bandwidth by the STAFF and LAB class rate=625 Kbps

Figure 17: Testing for total utilization by individual classes.

5.2.3 Testing for inter class borrowing.

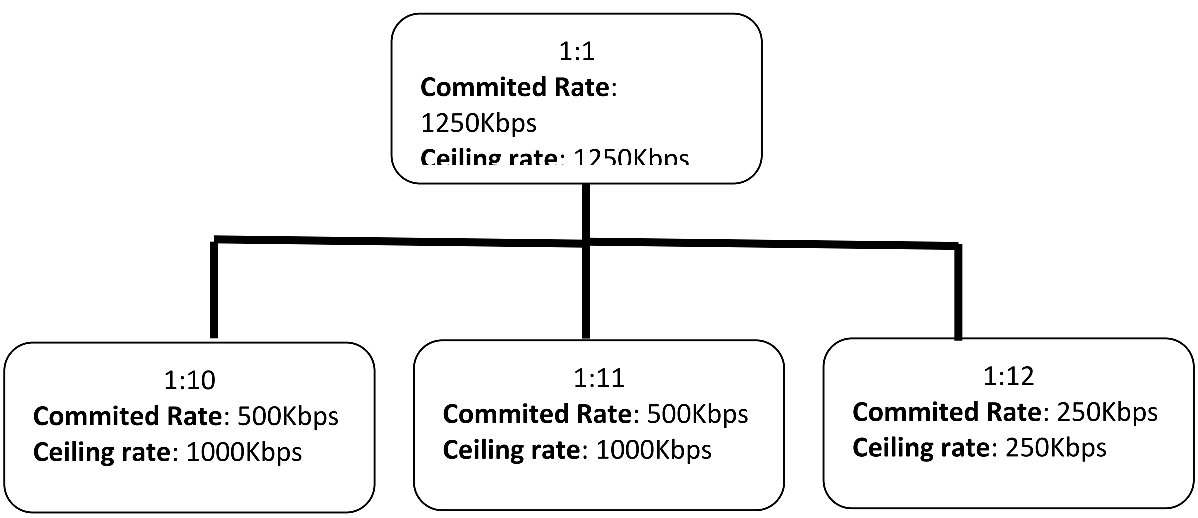
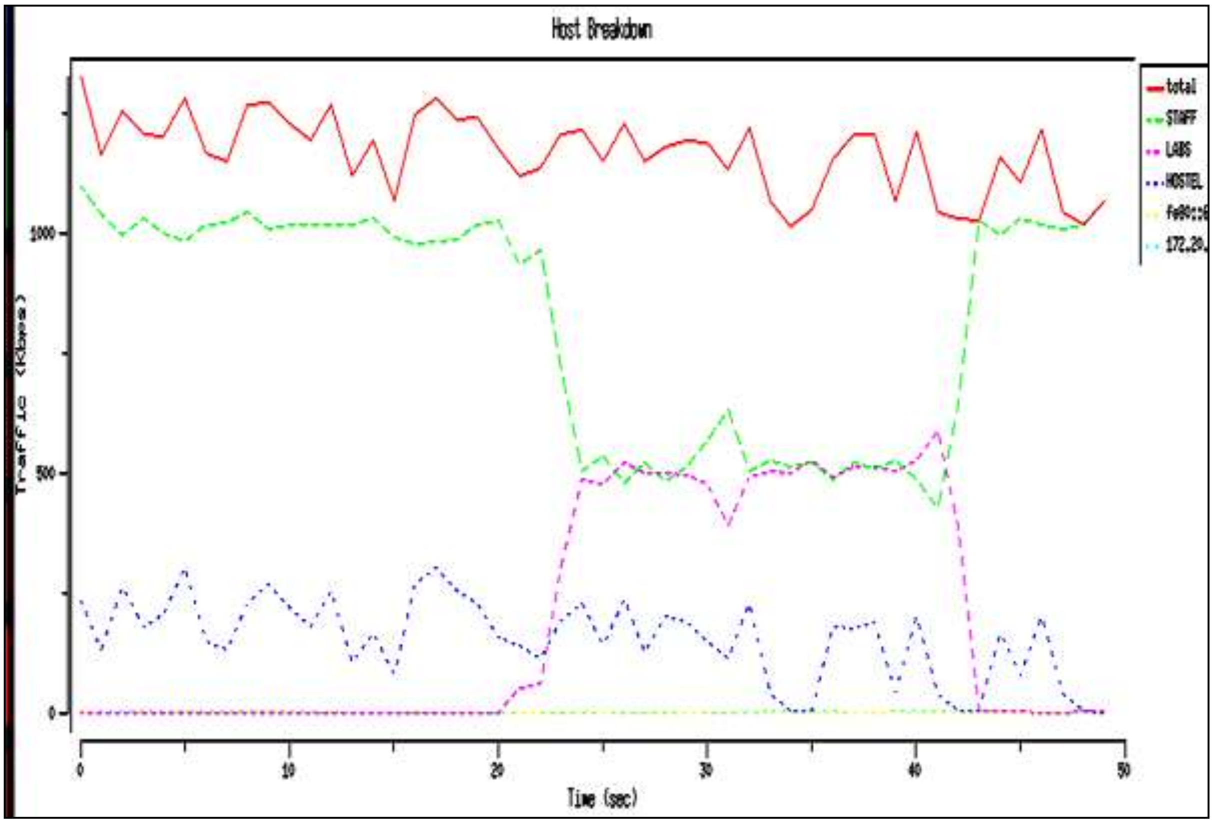


Figure 18 Classification Hierarchy

The prototype was designed to support interclass borrowing to ensure optimal usage of internet bandwidth by reducing bandwidth wastage. When one class is not using its full share of bandwidth allocate to it, interclass borrowing is activated allowing classes within the same hierarchy to use excess bandwidth if required. We used the bandwidth sharing hierarchy shown in the figure 16 .The test experiment was set up as follows.

i. We created classes 1:10, 1:11, and 1:12 with 1:1 as their parent class.
ii. The parent class 1:1 was assigned a rate of 1250Kbps with a ceiling rate of 1250 Kbps.
iii. Classes 1:10 and 1:11 were allocated a committed rate of 500Kbps with a ceiling rate of 1000Kbps.
iv. The class 1:12 was allocated a committed rate of 250 Kbps with no ceiling rate. Meaning that it could not borrow bandwidth.
v. Then downloads were started from staff and lab hosts at time t=0
vi. Uploads were started from hostel host at time t=0
vii. At time t=22 downloads from the Labs host was started.
viii. Finally at time t=43 downloads from the Labs host were terminated.

Figure 19 Evaluation for bandwidth borrowing



From Figure 19 we note that:

i. Class 1:10(staff) which represents traffic to staff host was able to utilize all 1000 Kbps up to time t=22 when downloads from class 1:11(Labs) were started.

ii. When downloads from class 1:11(Labs) were started, the consumption of class 1:10(staff) dropped to 500 Kbps as expected. This indicated that class 1:10(staff) was able to release borrowed bandwidth when a class within the same hierarchy needed it.

iii. The figure further shows that class 1:12(Hostel) was not able to borrow any bandwidth since it was not assigned a ceiling rate. This further indicates that bandwidth borrowing was implemented by use of the ceil keyword as claimed in the design.

The tests for bandwidth borrowing was set out with the aim of assessing the level of inter class bandwidth borrowing. The test results in figure 18 indicate that bandwidth borrowing between classes was achieved.

5.3 Conclusions

This chapter presented the results of bandwidth manager prototype testing. The chapter started by presenting the results for the study of Meru Technical Training Institute which was carried out in order to gather the prototype design requirements. The evaluation experiments were carried out on test network simulating Meru Technical Training Institute network. The results from this experiments established that the prototype was able to manage bandwidth through traffic classification and bandwidth allocation. The experiments also showed that the prototype was also capable of bandwidth optimization through inter class borrowing.

CHAPTER SIX

DISCUSSION OF FINDINGS AND CONCLUSIONS

6.0 Introduction

This chapter focuses on discussions on findings of the study of the Meru Technical Training Institute network as well as the prototype testing. The chapter also presents the critical review and recommendations for future work.

6.1 Status of internet access

The study revealed that there are differences in levels of computer access between the students and the staff. The study revealed that teaching and administrative staff enjoy more access to computers than students do. The findings also suggest that computers are being used mainly in Meru Technical Training Institute for administrative operations and less in the teaching and learning processes. This finding contradicts with the requirement in place for African tertiary institutions of the minimum of 10Mbps per institutions (INASP, 2010).The high student to computer ratio and low bandwidth indicates that the strain in resources would make bandwidth management ineffective.

6.2 Bandwidth Management strategies

The data collected revealed that the institution was not keen on bandwidth management. The systems administrator reported that he did not have a plan for bandwidth management, in addition to lack of skills to use existing technologies for effective bandwidth management, the systems administrator also reported that effective technical solutions were too expensive for the institution. This study argues that the best way to implement bandwidth management strategy is by managing user behavior. This argument is in line with Murizah and Hafizoah (2011) affirm that in order to optimize bandwidth, traffic management is essential. By controlling how much bandwidth that can be used a particular group of users reduces wastage.

6.3 Challenges to bandwidth management

The study revealed that the main challenge relating to bandwidth management in Meru technical training institute is the lack of appreciation for the importance of bandwidth management. With a congested network,acces to the internet becomes ineffective and therefore does not serve its role.INASP(2010) established that in order to optimize internet bandwidth any institution must recognize bandwidth as a resource that needs to be managed and conserved. The growing demands for bandwidth in Meru technical training institute require that the institute develop a strategic plan to manage its bandwidth. However, the study revealed that currently Meru technical training institute has inadequate bandwidth management activities which include only technical solutions. This finding is in agreement with Flickenger, Belcher, Canessa and Zenarro (2006) conclusions that an integrated approach of technical and user policy would be the most effective in bandwidth management.

6.4 Traffic Classification

As shown in the figure 15 all the hosts could use the committed bandwidth allocated to their respective classes, proving that the prototype could match IP addresses to their respective classes.The test for classification functionality sought to determine if the bandwidth manager prototype could classify traffic appropriately. The results of the study as illustrated in figure 15 suggest that the prototype was able to classify traffic as expected. These findings collaborate the idea of Hubert (2013), who suggested that the u32 filter which is part of the tc command is capable of packet classification based on IP addresses. Classification was done to make bandwidth allocation easier.

6.5 Bandwidth Allocation

From the figure 16 we notice that the prototype is accurate in allocating bandwidth both for uplink and downlinks. Every class was only able to consume only its allocated share. The allocation was done based on the stated parameters and as expected no packet flows to exceed their stated parameters .This finding accords with Kashihara and Tsurusawa (2010) observation, that the U32 filter can be used to classify traffic and allocate bandwidth effectively.

6.6 Inter Class Borrowing.

The tests for bandwidth borrowing was set out with the aim of assessing the level of inter class bandwidth borrowing. The test results in figure 18 indicate that bandwidth borrowing between classes was achieved. This feature of bandwidth borrowing was incorporated in the prototype to ensure bandwidth optimization by reducing any wastage. This finding is in agreement with Diacehu and scripcariuo (2010) assertion that a good network solution for bandwidth optimization should provide for bandwidth sharing. The bandwidth to be borrowed depends the ceiling value for a particular class. From figure 18 it shows that the staff class was able to borrow a rate equivalent to its ceiling rate. The hostel class was also not able to borrow anything since it was not assigned a ceiling rate. This finding collaborates with Morizah and Hofizoah (2011) findings that the restriction for bandwidth borrowing is limited to the ceiling rate.

6.7 Conclusions

Lack of efficient bandwidth management solution has been the major cause of wastage and misuse of internet resources in higher institutions of learning in Kenya. Proper bandwidth management is key to providing better services for any learning institutions important applications since it is not feasible to meet the increased demand for bandwidth by buying more. The study of Meru Technical Training Institute network has demonstrated that most network administrators do not take bandwidth management seriously. In this project we implemented a Linux based bandwidth management prototype for use n tertiary institutions. The design was based on data collected during the study of Meru Technical Training Institute network. The study of Meru Technical Training Institute network was done to collect requirements for the prototype. The prototype was designed and implemented to classify traffic, allocate bandwidth and allow for bandwidth borrowing between classes. Bandwidth borrowing was implemented to prevent bandwidth wastage which would result from packet dropping packets which have already traversed the internet. Instead of the packets being dropped, the needy class borrows bandwidth from other sibling classes. Tests were conducted to evaluate the prototype for classification, bandwidth allocation and bandwidth sharing. The results obtained from the evaluation of the three functionalities proof that the implemented bandwidth manager prototype is effective in bandwidth management. The working of the three functionalities implies that system administrators of tertiary institutions can be able to perform bandwidth management using the proposed prototype. Also since the prototype is implemented using open source tools it should be affordable to all tertiary institution network managers. The prototype was also designed using the desktop version of Ubuntu Linux which graphical user based and therefore not complex to use. This should be comfortable even for those network administrators who are not Linux certified so long as one has used windows operating systems. In conclusion the prototype is affordable, easy to use and effective in bandwidth management for any network administrator who would consider using it.

6.8 Critical Review and Reflection

The study main objectives of the study were to design, implement and test a bandwidth manager prototype for efficient bandwidth utilization suitable for tertiary institutions. These three objectives have been satisfied to a suitable extent. Section 2.7 of the literature review identified Cisco and Linux as the two most popular bandwidth control methods. Linux was proposed since it is open source and therefore readily available. Cisco routers were found to be equally effective but expensive.Ubuntu was used to implement the prototype on a test network simulating Meru Technical Training Institute network. The results of the tests have proved that Linux as a bandwidth manager tool would meet the tertiary institutions requirements. The results obtained from the testing section of this report have provided evidence that bandwidth management can be configured on a Linux gateway as desired. The classification evaluation was meant to establish if the prototype could classify traffic based on IP addresses. The results as depicted by figure 13 proved that classification was successful. The test for bandwidth allocation functionality was done with the aim of gaining insight on how the prototype would allocate bandwidth. As the results in figure 14 depicts, for the downlink bandwidth allocation was not efficient as expected evident by not so smooth curves. If the testing was to be done again it may be advisable to devise a more accurate way of assigning uplink bandwidth. The main objective of the study was to show how bandwidth could be efficiently utilized through sharing. As shown in figure 15, this part of the experiment did provide the expected results and sharing was successful. Class hostel was used as a control class to show that if a class is not configured for bandwidth sharing it won't be able to borrow any bandwidth. This proved that in order to optimize bandwidth borrowing, the borrowing parameter has to be configured. Due to lack of enough resources, the author was forced to use only three test machines and effects on scalability was not tested. The equipment worked well but the choice to use only three test machines needs to be examined. The main aim of the report was to create a bandwidth manager that would optimize bandwidth through sharing. An in depth investigation into various traffic control techniques was carried out to gauge the suitability of each method. The investigation and research uncovered that Linux could be configured to control bandwidth. The project has proved that Linux can be programmed to shape end user traffic in a manner suitable for tertiary institutions. It has also provided quantitative data on how traffic control using Linux can affect network traffic. It is hoped that anyone who reads this report and chooses to use the proposed prototype will be able to manage bandwidth effectively.

6.9 Recommendations for further studies

In the process of carrying out this study, several areas of further study have presented themselves. During the prototype testing, the testing was not done in a network emulating the Meru Technical Training Institute network. For anybody wishing to refine the prototype we recommend that the prototype be tested on a real world network environment. Also during the evaluation process only three hosts were used. We recommend that any future research should include a larger number of computers so as to be able to test the effect of scalability on bandwidth management. The study also targeted at coming up with an affordable bandwidth management solution. We would recommend that any further research should aim at establishing the effect of bandwidth management on utilization on resources such as memory and C.P.U usage by network devices.

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APPENDIX 1

The Complete Bandwidth Manager Prototype Script

```
#!/bin/sh
#
# Download traffic control
#
IP1=172.20.21.101
IP2=172.20.21.102
IP3=172.20.21.103
DEV=eth0
#
tc qdisc del dev $DEV root
#
tc qdisc add dev $DEV root handle 1: htb default 10
#
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 500Kbps ceil 500Kbps
tc class add dev $DEV parent 1:1 classid 1:11 htb rate 500Kbps ceil 500Kbps
tc class add dev $DEV parent 1:1 classid 1:12 htb rate 250Kbps ceil 500Kbps
#
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
#
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
#
echo;echo "bandwidth shaping for $DEV: successfull"

# Upload traffic control
#
DEV=eth0:0
#
tc qdisc del dev $DEV root
```

```
#
tc qdisc add dev $DEV root handle 1: htb default 10
#
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 500Kbps ceil 500Kbps
tc class add dev $DEV parent 1:1 classid 1:11 htb rate 500Kbps ceil 500Kbps
tc class add dev $DEV parent 1:1 classid 1:12 htb rate 250Kbps ceil 500Kbps
#
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
#
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
#
echo;echo "bandwidth shaping for $DEV: sucessful"
```