Quality of Service (QoS) in Optical Broadband Access and Metro Network Architecture

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DECLARATION

I declare that this dissertation "**Quality of Service** (**QoS**) **in Optical Broadband Access and Metro Network Architecture**", is my research work and it has not been presented or submitted for any degree in any other university. All materials used as source of information have been acknowledged in the text.

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DEDICATION

I dedicate this dissertation to the following people;

The Almighty God,

Late Mr. Joseph Kolwane, Father,

Mrs. Molly Kolwane, Mother,

Mr. ThatoyaoneKolwane, Brother,

Mrs. Poppy Mahole, Sister.

Thank you for showing the family love and emotional support "blood is thicker than water"; May the Almighty God continue to reward you abundantly with gift of life to make you enjoy the fruit of your investments. I dedicate this achievement to you all.

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ABSTRACT

Fibre-Wireless (FiWi) is a hybridized Dense Wavelength-Division Multiplexing-Passive Optical Network (DWDM-PON) with Worldwide Interoperability for Microwave Access (WiMAX) as a means of providing higher bandwidth and efficient services. This research sought to develop and implement a framework for improved Quality of Service (QoS) for FiWi observing some specific QoS parameters namely: throughput, page response, traffic sent/received, traffic quality and traffic fluctuation. The methodology used was the experimental setup with simulation using OPNET. Two experimental beds were setup one with and the other without QoS using http heavy browsing. The research focused on converging DWDM-PON wired network as a backhaul to WiMAX wireless network in order to design a robust framework for QoS evaluation in FiWi. Broadband networks are widely used and dominate the access segment and support point-to-multipoint full duplex emulation systems allowing communication in both directions (i.e., uplink and downlink) simultaneously up to 1Gbps per channel per fibre. This research is based on providing QoS broadband access provincially covering both rural and urban areas. The obtained results show that high bandwidth allocation, low latency and reduced delay are key factors for achieving QoS in FiWi metro network architecture. FiWi accelerates triple play services, reducing core network traffic and ensuring very low latency and delay. Expedited forwarding (EF) and weighted fair queuing (WFQ) scheduling algorithm were used to maintain and show QoS traffic.

The implications are there is a performance bottleneck in the existing broadband networks, this is central problem for both wireless and optical access. It causes packets to drop in the network because of network congestion. Existing copper networks offer limited diverse services and are postponing FiWi implementations. The beneficiaries of this study are the people of the North West province because this dissertation gives an implantation of how a FiWi network can be deployed. This dissertation educates the research community that FiWi is the future broadband network that provides QoS. BE service has less end-to-end delay when compared to WFQ due to the fact that WFQ needs to firstly assign packets with relevant weights before transmission. WQF is the best service supporting QoS.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADSL   Asymmetric Digital Subscriber Line

AP   Access Point

BPL   Broadband over Power Line

CDMA   Code Division Multiple Access

CPE   Customer Premises Equipment

DSL   Digital Subscriber Line

DSLAM   Digital Subscriber Line Access Modelers

DWDM   Dense Wavelength-Division Multiplexing

FiWi   Fibre Wireless

FSO   Free Space Optics

FSOC   Free Space Optical Communication

FTTB   Fibre to the Business

FTTH   Fibre to the Home

FTTP   Fibre to the Premises

FTTW   Fibre to the Wireless

IEEE   Institute of Electrical and Electronics Engineers

ITUT   Telecommunication Standardization Sector of the International Telecommunication Union

LMDS   Local Multipoint Distribution Service

LOS   Line-of-Sight

LTE   Long Term Evolution

MMDS	Multipoint Multichannel Distribution System
NGNs	Next Generation Networks
NLOS	non Line-of-Sight
OFDMA	Orthogonal Frequency Division Multiple Access
ONU	Optical Network Unit
PONs	Passive Optical Networks
POTS	Plain Old Telephone Service
QoS	Quality of Service
RF	Radio Frequency
SA	South Africa
SCTE	Society of Cable Telecommunication Engineers
SDSL	Symmetric Digital Subscriber Line
SHF	Super High Frequency
TDM	Time-Division Multiplexing
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunication System
UWB	Universal Wireless Broadband
WBAN	Wireless Body Area Networks
WDM	Wavelength-Division Multiplexing
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WPAN	Wireless Personal Area Network

Chapter One
Introduction and Background Information

1.1. Introduction

Broadband access solutions can be classified into two categories namely: fixed line technologies and wireless technologies. In recent times broadband has been identified as a key priority for South Africans by Telkom the Internet Service Provider (ISP) and mobile network operators, but in this research we are focusing and looking closely at hybrid broadband access called fibre-wireless (FiWi) access network. FiWi broadband network architectures are powerful and robust access paradigm enabling and supporting future technological developments of both wireless and wired broadband access. It pays particular attention to wireless mesh networks and optical fibre networks [1]. The main problem in the existing architectures is bandwidth allocation and network interference. The existing networks offer limited triple play services.

Orthogonal Frequency Division Multiple Access (OFDMA) is a broadband wireless access (BWA) network that allows simultaneous low data rate transmission from several users thus providing opportunities for convergence with other wireless technologies and wired technologies. This architecture outperforms the existing Passive Optical Networks (PON) [2-4]. OFDMA improves robustness in fading channels and minimizes interference whilst offering excellent radius coverage [2-4]. It improves robustness by utilizing narrow beam antennas to protect the radio link from interference and Orthogonal Frequency Division Multiplexing (OFDM) reduces crosstalk in signal transmissions [5]. Interference can decrease the overall network performance in a spectrum sharing system. FiWi which is sometimes called FibreToThe Wireless (FTTW) is the convergence of optical fibre as the backhaul and nomadic wireless technology. Optical fibre in the FiWi architecture replaces Digital Subscriber Line (DSL) as the backhaul because DSL use copper wire to transfer digital signal over standard telephone lines although using broadband communication service. Fibre is more robust and faster than copper wire.

This research was based on the available architectures for both the optical and wireless broadband access technologies. We focused on the hybrid FiWi access network in a metro network architecture and then considered several main issues concerning these architectures: the behaviour of transporting protocols including load balancing, end-to-end Quality of Services (QoS) support and the QoS parameters. Optical fibre continues to offer unlimited

bandwidth in broadband connectivity as the broadband revolution continues to provide services such as voice, data, and video the triple play services in a single connection [6]. The bandwidth required in Next Generation on Demand Applications (NGoDAs) such as Video on Demand (VoD) is large. This exerts pressure on bandwidth provisions in broadband access networks, thus increasing demands for higher bandwidth[6]. We considered a hybrid network optimization topology that includes QoS support [6].

Copper broadband networks mainly suffer from factors such as cost constraints, durability and maintenance. This factors contributes in making optical fibre broadband access networks have multiple advantages. Gradually in most cases copper is being replaced by optical fibre. Our focus was based on optical broadband access because it offered almost limitless bandwidth capabilities; hence technologies such as copper using Digital Subscriber Lines (DSL) do not have excellent reliability [6]. It is increasingly becoming cheaper to install optical fibre technologies. Proper design can make fibre comparable and less expensive. Investing in fibre increases bandwidth and avoids electromagnetic interference problems. Copper networks degrades as a signal is carried from the central office (CO). Fibre high speeds and longer distance capabilities allow new network architectures and protocols to make copper look expensive. Fibre technology is energy efficient when compared to copper technologies and also continues to offer ultimate broadband connectivity. Optical broadband access provides Passive Optical Networks (PONs), because service demand applications in the internet introduced and forced the penetration of fibre networks into the access network segment where there is a huge growth in the internet traffic and bandwidth.

PON is a robust broadband access network using optical fibre. PON architecture consists of the following three network components: the Optical Line Terminal (OLT), passive splitter and the Optical Network Unit (ONU)[7]. OLT resides in the CO and is known for electrical signal conversions used by the Internet Service Provider (ISP). It connects up to 32 ONUs and is used to connect the optical access network to the metro backbone. The signal from the CO is split by the passive splitter to the ONU in a PON. ONU provide Fibre To The Home, Business or Wireless (FTTH/B/W)[7]. PON architectures can transmit broadband triple play services using the optical broadband access in metro network architecture over guaranteed throughput level.

The Transmission Control Protocol (TCP) is a reliable transport protocol that supports QoS in terms of defined end-to-end connections, in a hybrid FiWi network topology [6]. TCP is

linked with mechanisms called packet aggregation in order to reduce the overhead associated with each transmission in the TCP segment to avoid losing many acknowledges (ACKs) in the TCP throughput[8]. The analysis of QoS support, load balancing and TCP behaviours were recommended by authors in [6] to be used in hybrid architectures. Optical Network Units (ONU) and the WiMAX base station have been integrated into one piece of equipment for matching the QoS throughput level to the QoS support mechanisms [8]. ONU is situated near the subscriber and it allows PON to converge with other existing network domains. It operates the same way as NID (Network Interface Device). The WiMAX and PON classified as a hybrid access network that utilizes mechanisms such as scheduling algorithms for resource allocation with multiple priority traffic classes [8]. These QoS parameters (throughput, delay, jitter, bandwidth and packet dropped) can be negotiated during connection establishment.

A metropolitan network architecture offers a full broadband service that enables residential, business, and mobile users to access it anywhere. This scenario shows that metro networks can supply triple services (data, voice and video) using QoS parameters because metropolitan networks use fast and high speed connections such as optical fibre, while delivering uncompromised efficient access from the network operator. The metro network uses transport protocols for moving traffic between the access segment and service devices [9]. In metro areas the FiWi network architecture optimization is important because it offers alternatives regarding cost effective constraints and highest achievable performance [9].

FiWi enables broadband to transfer and transverse data at the speed of light, thus improving broadband speed for all users and keeping subscription rates affordable. Users can benefit from a faster connection on online activities such as internet banking and on demand applications. Authors in [7, 8] stated that with optical broadband you can get download speed of up to 100 megabits per second (Mbps) or even faster. Figure1.1 is an example, in standard broadband a user can download an HD movie at an average speed of 10 Mb for 24 minutes, whereas in optical fibre broadband you can download the very same original HD movie at an average speed of 43 Mb for 6 minutes, this shows that optical broadband is four times faster than the standard broadband [8].
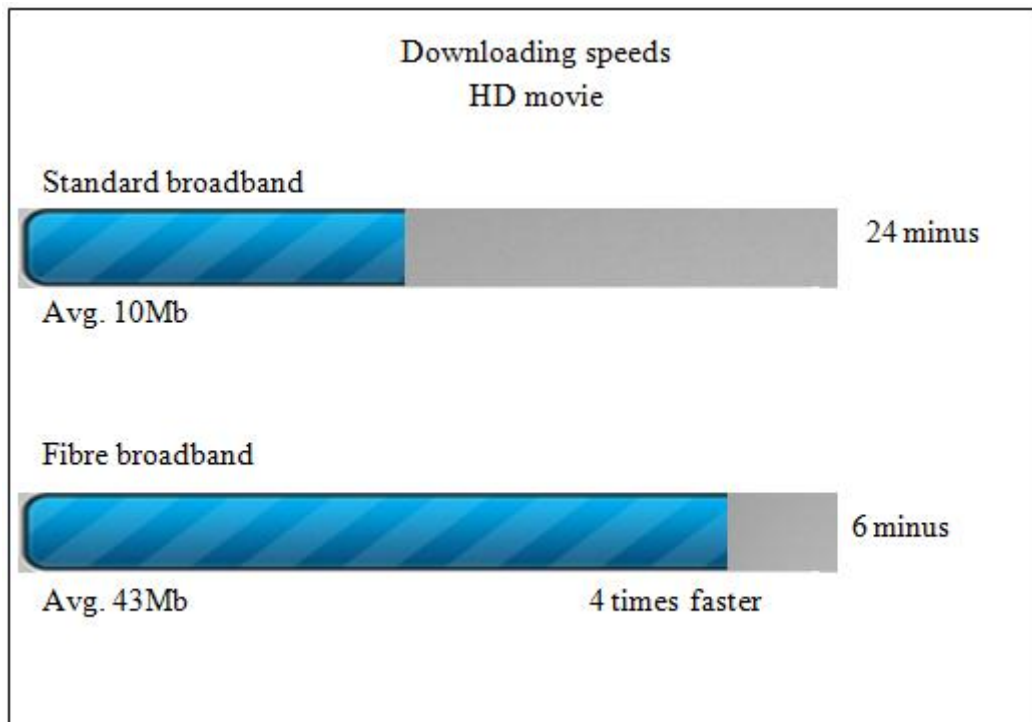
Figure 1. 1: Standard V/S Optical broadband [8].

1.2. Background Information

Hybridizing the wired network with wireless network converges the access and metro network into a single network to provide high data transmissions in radius coverage of up to 100 km. Converging DWDM-PON with WiMAX consolidated a metro network into an access network. Broadband access networks are the best technique in enhancing bandwidth in order to reduce access bottleneck[10]. Traditional access networks are mainly based on copper cables[11]. QoS offers the degree of satisfaction to the user of the service[12]. QoS is a solution for reducing the performance bottleneck in the access and metro networks. FiWi has multi gigabit network capacity which is an important characteristic of broadband access. FiWi has better network stability and resilience as well as providing higher network capacity.

Hybrid FiWi broadband access is the latest broadband standard, converging WiMAX and optical fibre network domains. For high efficiency in the WWAN, the wireless network must consist of an optical fibre backhaul from the ISP network (e.g. Telkom). This convergence will result in perfect metro network architecture. We need to have a powerful and faster backbone behind the wireless network and that backbone will be the optical broadband. This is how these two network domains can improve QoS. FiWi offers gigabit bandwidth with limitless transmission capacity that makes it easy to start accessing digital content on a single node.

The South African government has identified expanded broadband access as the key priority in the rise in broadband penetration. It also mentioned that the benefits and the affordability of broadband are linked to economic growth and job creations[13]. The backhaul of the wireless network architecture will be an optical fibre from the ISP network and the wide geographical area will mostly be covered by wireless networks merged with optical broadband access within the metro network architecture. It is necessary for FiWi network to have various QoS requirements because this type of network is designed to carry heavy traffic and it also deals with routing protocols [1]. The hybrid broadband access architecture has to account to the specific constraints (e.g. cost, bandwidth, throughput, etc.).

There are many contributions towards the integration of Optical Network (ON) in the internet of today. Wireless technologies are based on the standards such as IEEE 802.16 (WiMAX) and IEEE 802.11 (Wi-Fi). These standards have allowed for convergence of PON and wireless technologies in the metropolitan and access segments. Optical broadband access is preferred over copper for many reasons including safety, scalability, cost constraints and radio frequency (RF).

The two major standard groups which are the IEEE and the ITUT together with organizations such as SCTE, have developed standards for carrying signals over a PON architecture. The oldest standard was based on Asynchronous Transfer Mode (ATM) protocol. ATM-based PON (APON) are connection oriented and use fixed size packets called cells which cause delay when transporting high bandwidth services[14]. The strong growth of Internet Protocol (IP) in the access network replaced ATM protocol. After the use of ATM protocols then came a new approach referred to as broadband in the PON architecture (BPON)[15]. Broadband in the PON architecture (BPON) provided downstream bandwidth and upstream traffic. This standard accommodated high data rates. The latest standard called the gigabit PON(GPON) is better than BPON in total bandwidth and bandwidth efficiency through larger variable-length packets. Multipoint Multichannel Distribution System (MMDS) architecture has been around since 1970 as an alternative to cable TV[8, 15]. However, now there is a solutioncalled WiMAX that offers wireless internet connections to local areas and is able to transmit signals within a range of 100km[6].

The WiMAX forum describes WWAN as the integration of Wi-Fi technologies that offer internet coverage over wide geographical areas and offers wireless broadband connectivity that provides high speed. The WiMAX (IEEE 802.16) can offer services such as wireless

internet access and computer networking access over a wide area using fixed wireless dishes [6].

1.3. Problem Statement

The main problems on the internet today are mainly in the access segment because, in most cases, the user is limited from accessing diverse services. Factors that limit the users form accessing diverse services are limited bandwidth, network interference and lack of QoS. The network of the future has to improve the efficiency and capacity of broadband access technologies, so as to widen the bandwidth since service demands are forever increasing. The metro network faces the following three challenging tasks: the metro convergence challenge, the metro flexibility or compatibility challenge and the metro cost challenge [8, 9]. FiWi solutions face critical challenges that are focused on determining a feasible, scalable and resilient architecture [1]. The other problem is that most access networks are based on copper (mainly DSL) and coaxial cables [6, 8]. In the future, all the network architectures should start implementing the optical and wireless broadband access approach that support QoS. Broadband access architectures should also incorporate adequate internet access and allow the integration of resource allocation to all users [8].

The WiMAX and PON convergence is an innovative architecture that is based on heterogeneous technologies in the context of Next Generation Networks (NGNs) where there is QoS support and metro access integration[8]. The integrated support of QoS, manages end-to-end QoS requirements across the heterogeneous metropolitan access architecture [8]. The network of the future faces several challenges, among them, the task of transporting an increasing volume of burst internet traffic with a very low bandwidth. These challenges will be influenced by factors such as DSL copper cable solutions. WiMAX, as well as Wi-Fi and other emerging wireless technologies come with several limitations such as air pollution, microwave oven, cordless phones, effect of sun transit, attenuation due to rain and direction of antennas among other factors in the access segment [16].

Hybrid access network topologies pose new challenges that require novel planning approaches [8, 16]. We are doing hybrid FiWi broadband access to be aware of how multimedia content travels in the network architecture without affecting the process and movement of data or other applications using optical and wireless broadband accesses and delivering quality, clear information and reduced delay time. Wireless networks have several challenges such as distance limitation, costly installations of P2P systems, loss of signal

strength due to LOS wireless technologies, bad weather conditions such as high winds, hail and lightning.

1.4. Research Questions

The research conducted here gave answers to the following research questions:

1. How should the hybrid FiWi (FTTW) architecture offer triple play services (voice, data and video) in multimedia content forms?
2. How should one expect to avoid or reduce chances of distance limitations and can the architecture be resilient and overcome obstructions such as natural disasters, things beyond our control like poor weather conditions?
3. Is integrated QoS support compatible in this architecture and does it maintain levels of security, user mobility management and cost effectiveness?

1.5. Research Goal

The main goal of this research was to evaluate QoS in optical and wireless broadband access in a metro network using the hybrid FiWi (FTTW) architecture.

1.6. Research Objectives

In order to achieve the main goal for this research, the following research objectives were formulated:

1. Design a metropolitan network architecture that integrates the hybrid FiWi (FTTW) broadband access.
2. Simulate the integrated QoS support architecture and traffic packets as well as transporting protocols as priority of QoS.
3. Provide prototypes that will automatically plan the topologies of the hybrid FiWi (FTTW) access network taking into consideration the services and user parameters in (2).

1.7. Research Methodology

The methodology used in this research is as follows:

1.7.1. Literature Survey

A literature survey was conducted, in which we enhanced our knowledge within our framework of study in order to guide our current research. Our research was based on the following subheadings: the fixed line- and the wireless, mobile broadband access technologies. We will deploy and research on the hybrid broadband access architecture in a

large geographical area. The hybrid broadband will be the convergence of two related network domains: the wired domain (optical fibre) and the wireless domain (WiMAX). The optical fibre will be used as the backhaul whilst WiMAX will deliver and transmit reliable QoS broadband access to multiple users in metro network architecture.

1.7.2. Experimental Design

The experimental setup will consist of the following:

1. OPNET modeler simulator for the simulation of the network.

2. The simulator in (1) will be used to simulate the QoS hybrid access network.

1.7.3. Proof of Concept

This concept will consist of the following:

1. Provide evidence on the hybrid broadband access architecture that will implement a point-to-multipoint based QoS network in a metro network architecture by showing the results in a form of simulation.

2. Evaluation will be based on performance of the implemented prototype; the QoS hybrid broadband access architecture and simulation results will be generated and analyzed.

1.8. Dissertation Contributions

The main contribution of this dissertation both to academia and research community is in the design and implementation and performance evaluation of a FiWi hybrid broadband Networks.

The experimental setup and the methodology used in this research has been presented as a work-in-progress paper in the proceedings of the 2016 Southern Africa Telecommunication Networks and Applications Conference (SATNAC), at Fancourt, George, Western Cape, South Africa, 4 - 7 September 2016.

1.9. Research Limitations

OPNET modeler version 14.5 does not offer optical fibre for high speed transmissions hence we also used PPP-adv link because this link is used over many types of physical networks including fibre optic links using DS3 data rates.

1.10. Dissertation Summary

This dissertation will consist of the following chapter outline:

1. **1.** Chapter one : Introduction
2. **2.** Chapter two: Literature Review
3. **3.** Chapter three: Experimental Design
4. **4.** Chapter four: Results and Discussion
5. **5.** Chapter five: Summary, Conclusion and Future work

CHAPTER TWO
LITERATURE REVIEW

2.1. Chapter Overview

In this chapter we provide an overview on optical fibre and WiMAX broadband access technologies. We compare the fixed and mobile broadband access technologies and also identify problems concerning these technologies. We discuss how convergence of the two access domains, i.e., the wired and wireless access network domains are used. We will also discuss their compatibility. Lastly, we conclude with related work on the evolution of performance by the IEEE 802 broadband standards in metro network architectures; focusing on the QoS of the hybrid architectures such as FTTW and FiWi.

2.2. Overview of optical fibre and WiMAX broadband access technologies

We highlighted the key concepts of the two access domains: the wired and wireless domains.

2.2.1. Optical fibre

Optical fibre is a very thin piece of flexible glass which is smaller than a strand of human hair, encased in protective encryption/code in which a laser beam is used to carry digital signal [16]. PON is a type of network that uses WDM or TDM in a fibre optic communication by multiplexing a number of optical carrier signals onto a single optical fibre using different wavelengths of laser light[17, 18]. The main advantage of WDM PON is that it offers two bidirectional communication systems: the simple full duplex and the full duplex emulation. The simple full duplex is used in a P2P system. However, since we are implementing metro network architecture we will use a full duplex emulation because it uses a point-to-multipoint system [17, 18]. With FTTH use passive splitters in a PON to implement a point-to-multipoint system. The system will use a full duplex emulation since it allows communication in both directions (e.g. uplink and downlink) simultaneously up to 1Gbps per channel per fibre[6, 17, 18].

Nowadays PON architectures are based on WDM, thus allowing the implementation of OBS technology in the metro segment [18, 19]. Optical communications have three main approaches particularly optical switching: OCS, OPS and OBS [19, 20]. OCS uses a dedicated wavelength on each link from source to destination. Once there is a connection setup the packets ingress and egress the nodes in an optical network and the packets need to

be converted to electrical form for convenient routing decisions[20]. OPS is the optical domain which groups all transmitted data into packets to minimize the transmission latency and optimize the use of channel capacity available to increase robustness of communication. OPS uses OEO conversions to process the overhead data before the data payload is transmitted to the next node. It must first wait in the fibre delay lines [20, 21].

The next generation switching paradigm called the OBS, is an alternative switching architecture since it combines the merits of both the circuit and packet switching paradigms because it is used to design and deploy the WDM networks [20-22]. OBS architectures support burst traffic and assemble the packets that have the same constraints (e.g. the same destination addresses)making a burst scenario out of the same constrain(ed) packets at the ingress node. The burst is assigned to a wavelength channelbefore being transmitted as a burst of data. At the egress node the burst data is disassembled back into original packets routed to their respective destinations [20-22]. OBS networks aim to improve the use of optical network resources by providing unlimited bandwidth capacity and easier interconnection to other existing WDM networks, thereby allowing full duplexing methods that have been deployed in wide geographical area networks [18, 19]. OBS is an optical switching approach hybrid that efficiently allocates resources for burst traffic.

For the future of optical networks, all the three optical switching paradigms, namely OCS, OPS and OBS have to coexist and work together to support QoS since it is the central objective in metro network architecture. The hybrid architecture (FTTW, FiWi) utilizes heterogeneous signals and different protocol formats, bit rates or configurations [21]. The coexistence of optical switching paradigms plays a vital role in increasing transparency in the network, so as to eliminate electronic bottlenecks to allow real time applications in the optical network that have dynamic traffic demands [21]. The merits of the optical switching technologies coexist to offer high bandwidth and high performance transmissions in burst traffic [21, 22].

DWDM-PON use OBS and QoS schemes to minimize latency and avoid the use of optical buffers. OBS supports WFQ by offering fairness among the network traffic types enhancing QoS[23]. The cables do not corrode or rust hence a single optical medium can reach speeds of up to 26 Tbps which is 26 000 Gbps. National Broadband Network (NBN) optical infrastructures are supposed to last for at least 60 years or more, it allows upgrades and if a

new or faster optical broadband emerges it will be placed and installed at the end of the NBN broadband structure (e.g. in our homes, curb and business) [16].

WDM-PON can provide 16, 32, 64 or even more wavelengths. However, DWDM-PON transmits free packet loss in a bidirectional (e.g. upstream and downstream) long reach 64-channel of more than 100 Mbps per channel through 70 km of a single fibre. DWDM-PON have overall capacity by using up to 80 separate channels or wavelengths and it spaces the wavelength more closely than WDM[14]. The service providers can configure DWDM to provide high bandwidth using the Add/Drop Multiplexer (ADM) system component. ADM adds new wavelengths to the network or drops some wavelengths at the terminating point. The adding and dropping of channels has a significant impact on the signal quality. DWDM signal can be transported in two directions: unidirectional and bidirectional. This depends on the required bandwidth and the availability of wavelengths[14].

Other researchers investigated the DWDM-PON network using Chromatic Dispersion (CD) compensation as an effective way to solve the performance bottleneck problems found in the access network. CD compensation improves the performance of high-speed DWDM-PON by offering quality transmitted optical signal and passive optical network reach[11]. It minimizes the optical pulse distortion and broadening in DWDM-PON because data transmission rates and distance are limited by the interference of wider and adjacent pulses. CD without compensation limits the maximum reach of DWDM-PONs. In order to achieve good QoS, DWDM provides additional capacity to existing fibre. Low maintenance costs are achievable because of fewer components in the optical networks [11, 14].

2.2.1.1.   Fundamental problems of Optical fibre

There are a number of problems associated with internet traffic today. The performance bottleneck in the broadband access network is the central problem for both wireless and optical access technologies. The OBS architectures are affected by burst traffic in the core network. There are unavoidable collisions with no buffers, which may cause low network utilization and loss of information [22]. There are remedies such as wavelength converters and FDLs that reduce collisions in burst traffic. Such solutions in OBS PON systems remain quite expensive and still affect performance [22]. WDM-PONs utilize analog video overlay rather than digital video overlay [24]. Full duplex emulation supports TDM and FDM, the full duplex methods and it can be used in a P2MP systems [24].

The rising energy prices and climate change force broadband access technologies to use energy efficiently, creating awareness in reducing the energy consumption [25]. PONs can also ensure the lowest energy consumption per subscriber of 0.2 to 0.8 Watts. Therefore, DWDM-PON use packet-based IP traffic to reduce power consumption [26]. WDM-PON solutions waste bandwidth due to the lack of flexibility[27]. The convergence of WDM with TDM offers flexibility benefits; however, DWDM transparently supports TDM[14, 28].

Laying underground fibre infrastructure causes more damage to that particular area where fibre is being laid. Digging up the area to lay new fibre cables can cause permanent soil erosion, damage to underground water pipes, even road traffic delay caused by digging up the road and pavement [29, 30]. South Africa has infrastructure systems such as sewer or drainage system that can house and secure fibre cables since optical fibre is water resistant. Fibre cables can run through the drainage system and pop at the right area since drainage systems are everywhere and the drainage system technique is very cost-effective. Countries like the United States of America are already utilizing this technique [30].

2.2.1.2. Comparison of fixed line technologies

Fixed-line technologies transmit signals via a physical medium (e.g. copper cables or optical fibre) that provides a reliable direct connection from the central office to the customer or connect directly to other networking domains such as wireless solutions for convergence purposes and fixed-line solutions are connection oriented [6].

PONs suffer from the physical channel impairments such as noise and attenuation but traditional technologies used Best Effort services to deliver triple play services and lack the capabilities of their TDM rivals such as SONET for management hence the Best Effort algorithm co-exists and works together with QoS parameters [24].

Access technologies based on copper for communication are being replaced by PON technologies using MAC protocols. PON solutions have been researched for over 20 years and unlike other access technologies, PONs consist of waterproofed optical fibre cables as the transmission medium, utilizing lasers and photodiodes as transmitter and detectors [24, 30]. DWDM-PONs are the new upgraded version of WDM-PONs [6, 24]. Fixed-line solutions are cost-effective and offer reliable connection when compared to wireless solutions [4, 17, 19].

In Table 2.1 we show a comparison of fixed-line technologies and this shows how major broadband solutions are compared based on spectrum usage, capacity, coverage/reach,

advantages and limitations [6]. In order to choose the perfect and reliable fixed-line technology, the technology depends on the type of services to be provided.Fixed-line solutions provide better penetration rates and the ability to converge with other networking domains [6].

Table 2. 1: Fixed-line technology comparison [4].

Technologies	Spectrum usage	Capacity shared	Capacity	Max range	Advantages	Disadvantages
xDSL family technologies (ADSL, VDSL, ADSL2+)	Up to 1.1 MHz and 2.2 MHz	NO	12 Mbps=0.3 km, 2 Mbps=4.8 km, (ADSL)	Max: 5.4 km	Uses existing POTs	Distance limitations
			26 Mbps=0.9 km, 53 Mbps=0.3 km, (VDSL)	Max: 1.3 km		
			26 Mbps=0.3 km, 7.5 Mbps=2.7 km, (ADSL2+)	Max: 2.7 km		
BPL	1-30 MHz	Yes	Max: 200Mbps, typically: 2-3 Mbps	1-3 km	Uses existing power-lines	Expensive power-line materials

PONs	THz	Yes	Up to 1 Gbps per channel fibre	20 km	Unlimited bandwidth	Requires new FAN overlay

2.2.2. Worldwide Interoperability for Microwave Access (WiMAX)

WiMAX is a wide area network technology that offers various diverse user services and on-demand applications. The user can download or watch triple play services anywhere within range and download applications faster than normal or engage in a multiplayer on-line 3D game for free. No more searching for restricted hotspots because WiMAX is fast, reliable and available broadband access within the radius coverage area. It is a point-to-multipoint mobile broadband encrypted wireless MAN; it covers large distances approximately 10km to 50km in radius. "The CEO of non-profit organization called project Isizwe, Alan Knott-Craig mentioned that this project is there to uplift our low income communities by providing free internet that will empower our communities through education, employment and social media activities; unfortunately high prices of internet put the internet of today out of reach for those who need it the most"[31].

Wireless and mobile access technologies provide consumer application nodes such as smart phones, portable gadgets and car navigation systems with internet connection [32]. The existing and upgraded wireless broadband architectures require reliability and capacity to guarantee reduced or minimal radio interference. The communication standards the ISA100.11 and wireless HART minimize interference in the wireless domain and they both contain TDMA protocol in their media access (MAC) layer, and TDMA is used to divide the shared frequency channels into different time slots to allow several users to share a medium, avoiding packet collision in a wireless network [32]. WiMAX is the future of wireless network architecture because it is used in order to minimize interference in a wireless network and it is equipped with mechanisms that can supervise the network [3].

We are using DWDM PON as the powerful backbone infrastructure of the wireless network (IEEE 802.16-e), since the wireless communication medium uses the duplexing methods such as time-division and frequency-division duplexing which are provided by the full duplex emulation. Full duplex emulation allows the two domains to converge whilst introducing QoS support to link the two domains into a single architecture in metro network architectures; so as to reduce costs and maintain resource efficiency [17, 18]. Wired communication links such

as fibre are costly to be deployed in rural areas. However, WiMAX architectures are suitable solutions to wirelessly cover areas where wired networks cannot reach and in those areas WiMAX will enhance QoS[33].

WiMAX enhances Wi-Fi for wireless network coexistence hence the user can connect to the network more often in more places without the use of restricted hotspots. WiMAX is built for the future of broadband networks because it transforms the user's mobile internet lifestyle. Today the most powerful available wireless internet technologies are based on the IEEE 802.11 a/b/g wireless standards family, which provide up to 54Mbps within a range of approximately 100m. If a wider coverage is to be achieved (e.g. for a university campus or an entire province) many wireless LANs must be interconnected [34].

The IEEE 802.16 working group developed a wireless metropolitan area network standard in 2004, called WiMAX providing data rates of up to 100Mbps using a single base station in a 10km radius. By the end of 2005, the WiMAX standard was improved by adding mobility and enhanced abilities to become the IEEE 802.16-e (WWAN).This provides much higher data rates for user applications on a country-wide scale [12]. WWAN WiMAX solutions have WPAN which interconnect PDAs, mobile phones and hands-free-kits within a distance of approximately 10 m at the speed of up to 1Mbps. WPAN standards include Bluetooth (IEEE 802.15.1), UWB (IEEE 802.15.3a) and ZigBee (IEEE 802.15.4) [12]. WiMAX standards also provide a lower level range called the WBAN which covers about a meter at the speed of up to 1Mpbs. WBAN interconnects a handset to an intelligent cloth or a health-care device using RFID and NFC[35].

The width of a radio channel is sometimes called the amount of spectrum. The wider the radio channel the greater the capacity of the wireless broadband system that runs on it [21]. A WiMAX uses a large amount of radio spectrum to run its applications. TDD technology is used to split up the capacity of a radio channel so that a large amount of the capacity can be available to the downlink than it is provided on the uplink. In general broadband technologies offer more capacity on the downlink when compared to the uplink (e.g. the latest technology 4G uses the TDD). WiMAX can offer relatively high data rates of 100Mbps in low frequency channel of 25MHz covering a large geographical scale under optimal conditions [36]. TDMA and FH protocols are used to avoid radio interference [23].

In 2008 the IEEE 802.21 working group supported and enabled handover between the same types of networks. Figure 2.1 shows the IEEE 802.21 Seamless handover between all

wireless standards. This allows handing over of wireless technologies of the IEEE 802…

standards such as IEEE 802.16-e, IEEE 802.16, IEEE 802.15.1 just to mention a few [21, 22].

The coexistence of wireless technologies working together is the future of broadband access

in the metro network architecture established by the IEEE 802.21 working group.
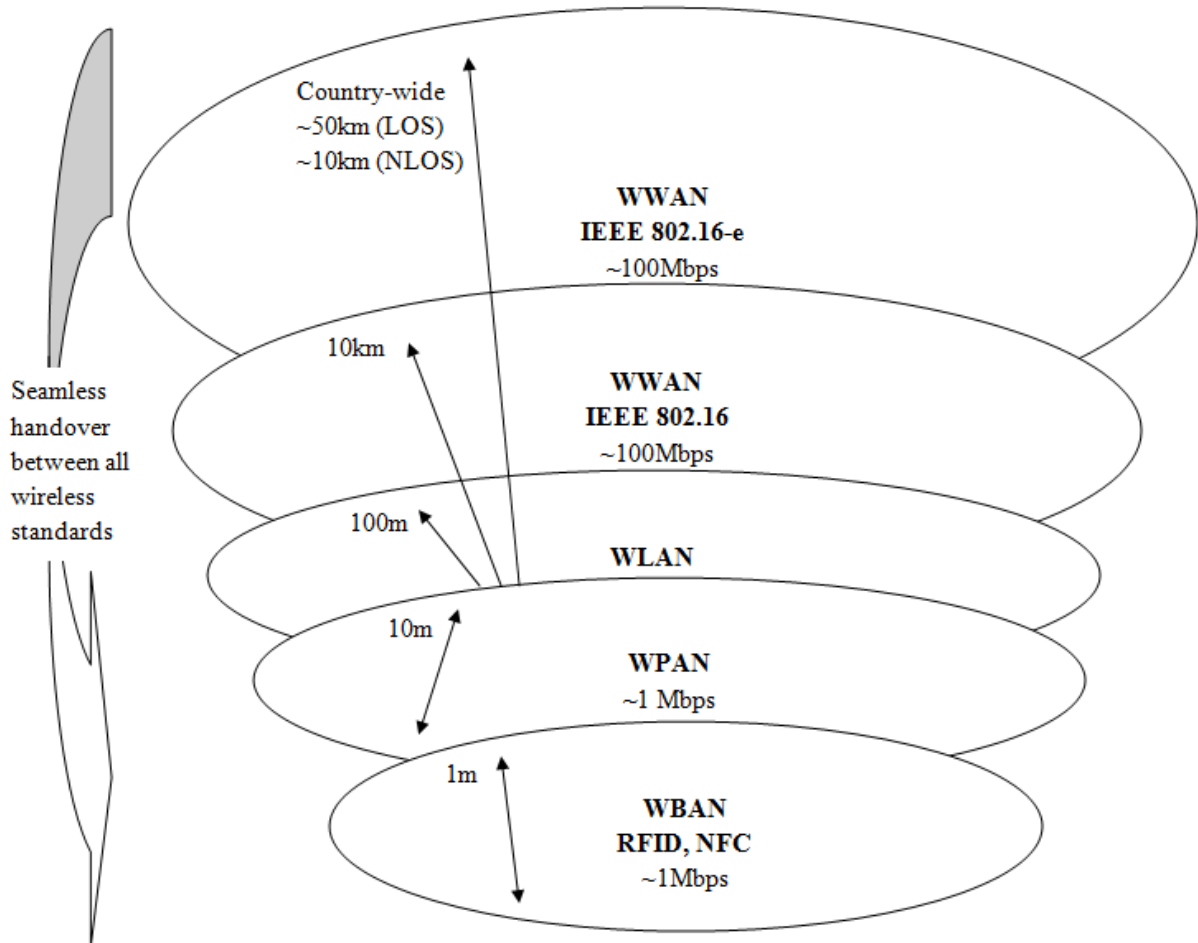
Figure 2. 1: IEEE 802.21 handover[23, 37]**.**

The IEEE 802.20 handover seamless converges all the wireless standards (e.g. IEEE802.16

d/e/j) and all the standards coexist in the WiMAX standard [2]. The currently existing

WiMAX technologies are based on the IEEE 802.16d (fixed stations) and IEEE 802.16e

(mobile stations) standards. The BWA of IEEE 802.16d is up to 50 km in a coverage area

beyond the conventional cellular network and that of IEEE 802.16e is 5-15 km within the

coverage area [2, 3]. Multiple-input multiple-output (MIMO) techniques have been used and

adapted by the IEEE wireless technologies (e.g. IEEE 802.16d/e/f standards) to improve both

the QoS and cellular coverage. This MIMO technique has been included in the point-to-

multipoint architectures [2]. WiMAX has mechanisms such as dynamic bandwidth allocation

(DBA) that provisions more bandwidth and power for the affected streams, when interference strikes the signal strength [3, 32].

Table 2.2 shows the comparison and performance of the latest generation LOS and NLOS fully featured WiMAX. We are using a fully featured WiMAX to provide broadband network coverage in a large geographical area (North-West province) to provide triple play services to a mass consumer base while the backhauling network to our WiMAX solution will be DWDM-PON architecture as a powerful backbone [6]. Next generation LOS and NLOS WiMAX architectures have unlimited bandwidth to offer ubiquitous high rate broadband services and will become the backhaul for Wi-Fi hotspots in the future[6].

Table 2. 2: Fully Featured WiMAX [4].

LOS not required (NLOS)	LOS required
2-11 GHz (similar to Wi-Fi)	Up to 66 GHz
More flexible	Stronger, more stable
Not as easily disrupted by physical objects	Less interference guarantees more bandwidth
Slower	Faster
Radius coverage: 4-10km	Radius coverage: 50km

2.2.2.1. Fundamental problems of WiMAX

WiMAX major limitations such as the effect of sun transit, attenuation due to rain and direction of antennas affect the wireless signal. Universal Mobile Telecommunication System (UMTS) frequency bands are still limited to a few Mbps user data rates; UMTS can still deliver triple play services at the speed of up to 2 Mbps to wireless nodes in metro network architecture through fixed, wireless and satellite systems. The more the users who come within the range of a base station the less capacity each user gets. In a wireless broadband network the capacity of a base station has to be shared; another challenge facing wireless and mobile networks is that when the user is closer to the base station the user is exposed to a stronger signal (higher data rates) otherwise the user experiences weaker signal (lower data rates) due to the fact that the user is further away from the base station.

WiMAX architectures experience several interference challenges such as air pollution, microwave oven and cordless phones just to mention a few [9]. For example, the user of a cordless phone close to a wireless device connected to the internet wireless may cause the wireless connection to drop [3, 38-40]. Wireless security cameras may also affect the wireless connection. Introduction of personal wireless networks may also introduce vulnerability into the main network (e.g. unauthorized wireless APs). Microwave ovens within the coverage range of a wireless AP, in most cases interfere with application such as video streaming and on-demand applications. There also exists a common interference called the neighbour wireless interference caused by a busy wireless connection near or next-door. Future mobile and wireless technologies face an avalanche of traffic volume, predicting the network traffic to increase by a huge volume over the next decade due to tremendous increases in the number of users [40].

2.2.2.2. Comparison of wireless broadband network technologies

Wireless technologies rely on radio or microwave frequencies to provide internet and other reliable connectionless communication between the customer and the network operators or private networks (e.g. mobile phones connectivity) [6]. There already exist P2P and P2MP systems to transmit wireless signals that require NLOS and LOS [6].

WiMAX is highly standardized as compared to previous wireless broadband technologies and will enhance Wi-Fi instead of replacing it. Wi-Fi utilizes unlicensed radio spectrum bands. Narrow bandwidth reduces wireless network performance when compared to wired networks. Wireless networks such as Wi-Fi are exposed to less frequency hence significantly reduced transmission range coverage [33].

In an access segment using Wi-Fi, the user may experience some challenges. In access contention for the AP; the subscribers will be competing for a single resource on a random basis thus reducing the total throughput due to distance limitations and possible interruptions caused by closer devices because Wi-Fi is sensitive to microwave oven and poor weather conditions. In a WiMAX solution users only have to compete once for initial entry into the network, by using scheduling algorithms (e.g. Fist-In, First-Out) to access the base station. The time slots allocated may enlarge or contract depending on the capacity of a single base station since in wireless and mobile networks; the procedure is that the signal from the base station is shared by the users [4, 9].

2.3. Demand analysis on the hybrid architecture

The demand for improving on the past generation architectures has led to the creation of converging quality architectures that are capable of providing broadband access services and higher bandwidth [41]. The hybrid infrastructure uses data communication devices such as bridges and switches, that mainly operate at the data link layer of the OSI reference model[42]. These network devices create and allow network communication by transmitting and receiving information [42].

The forever increasing demand for high QoS performance in the access segment has challenged researchers to propose and design innovative network architectures that can provide QoS broadband access by converging separate networking domains that can deliver high performance triple play services and on-demand applications. There already exists the penetration of fibre from the central office to the user hence the wireless domain of the WiMAX is significantly increasing BWA while minimizing equipment, operation and maintenance costs [36]. DWDM-PON integrates WiMAX to solve optimization problems of network capacity versus system cost. The link from the wireless base station to the CO has high bandwidth and low latency hence the optical fibre network is utilized as the network backhaul to prevent the broadband network complexity from reducing overall network performance[33].

The physical infrastructures of PON and WiMAX networks differ. However, converging the two infrastructures increases performance. Observing factors such as bandwidth, capacity and size, hence an efficient QoS hybrid broadband network is an agile network expected to offer seamless convergence of two networking domains [36]. Authors from [33]mentioned that FiWi architectures meet the demands of mobility and high bandwidth in a broadband access. FiWi is a promising area of research. It integrates optical networks such as Ethernet Passive Optical Network (EPON), Gigabit Passive Optical Network (GPON), TDM-PON, WDM-PON and DWDM-PON with wireless solutions such as Wi-Fi, WiMAX, Fourth Generation (4G), Long Term Evolution (LTE) and 5th Generation (5G) [33].

The Figure 2.2 shows Telkom's fixed-line network layout infrastructure in South Africa that is capable of enabling true convergence and it accounts for 80% of the total fibre footprint in SA, covering and reaching 147 000 km nationally [29, 43]. There already exist fibre-optical network infrastructures nationally provided by Neotel, Broadband Infraco, Fibreco, DFA, Sauren, Vodacom, MTN and Telkom [29, 43, 44].

The North-West province has underground Telkom fibre infrastructure but in order to utilize and access this fibre we first have to get legal permission and register with Telkom [24, 30].
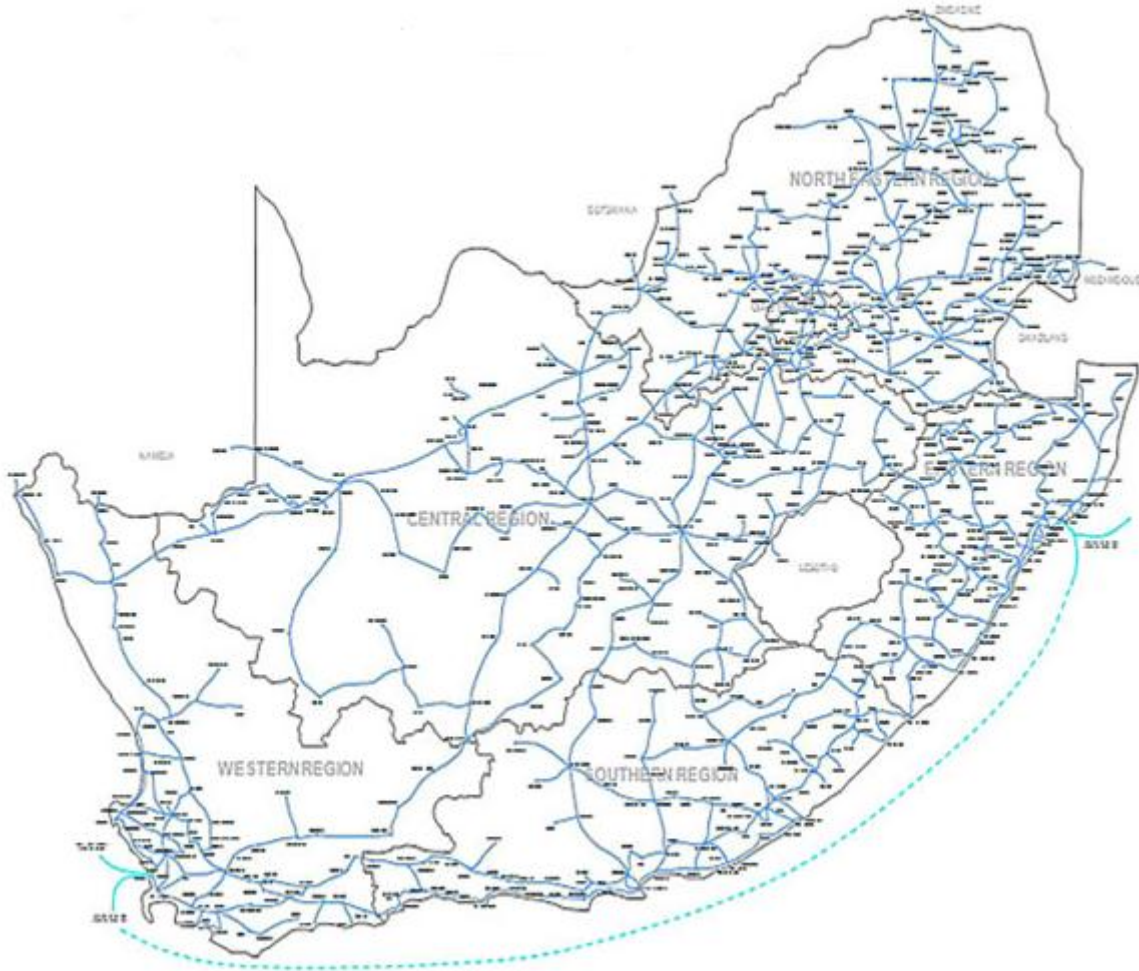
Figure 2. 2: Telkom fibre map [18, 27].

2.4. Related work

In order to comply with the expected future users' service demands, the broadband access technologies have to include mechanisms that integrate different technologies to incorporate adequate access to diverse services in a transparent manner and offer high level of QoS support in the network architecture [17]. PONs are classified into core networks, metro networks and access networks [45]. The backhaul of our hybrid architecture will be based on the DWDM-PON because DWDM-PON replaces the WDM-PON architectures to increase bandwidth over existing fibre optical backbones meaning multiple signals can be transmitted simultaneously supporting full duplex emulation methods (e.g. TDM and FDM) at different wavelengths on the same single fibre medium [19, 20, 44, 45].

Private network users in a hybrid broadband solution do not directly connect to PON technologies or the underground laid Telkom fibre infrastructure, but rather they connect to PONs through other intermediate access solutions from WiMAX such as APs and Wi-Fi solutions [1, 44, 45]. DWDM-PON solutions are the upgrades of PON technologies (e.g. EPON, BPON, G-PON, APON, WDM-PON AND TDM-PON) because of the fast-growing and bandwidth-hungry applications, as demand picks up also the research and development in PON technologies accelerates and meets the demands of the broadband network applications [24]. WDM-PON techniques separate upstream from downstream signals whilst providing virtually unlimited bandwidth from an access segment and the WDM-PON was firstly proposed by Wagner, this solution has several advantages such as high capacity, privacy and protocol transparency [24].

Different networking domains especially converging the wireless and wired networking domains, FTTW and FiWi are used to offer and provide unlimited broadband access in a MAN, and the main goal of this FTTW architecture is to reduce or maybe fix all the challenges experienced in the access segment by offering QoS in the access segment for end-users to gain QoE [6, 34, 44, 46, 47]. Bidirectional 64 channel DWDM-PON architectures obtain packet-loss-free transmissions and reach 80 km in transmission distance but other family PON solutions suffer from distance limitations and to increase the transmission distance require expensive equipment hence TDM-PON requires optical amplifiers and dispersion-compensation fibre (DCF) while WDM-PON lacks injection power of the broadband light source (BLS) [46].

The Table 2.3 shows bandwidth requirements for different IP services and it answers an often asked old question of: "how much bandwidth will be enough to provide triple services to an end-user?" This table shows that PON solutions are economically considerable and QoS parameters are still the central objective because QoS offers end-users the required bandwidth to access on-demand applications [24]. DWDM-PON architectures are capable of offering diverse applications (triple play services) of different bandwidth because this upgraded fixed-line technology is used to increase bandwidth over existing Telkom or Neotelfibre optical backbones [24].

Table 2. 3: Triple play services [17].

Applications	Bandwidth	QoS

Video	3.5 Mbps (SDTV)	Low loss, low jitter, constant bit rate
(SDTV, HDTV, UHDTV)	15 Mbps (HDTV)	
	3 Gbps (UHDTV)	High bandwidth, constant bit rate, priority scheduling
Telecommuting	10 Mbps	Best effort, bursty
Video gaming		Low loss, low jitter, bursty
Voice	64 kbps	Low loss, low latency, constant bit rate, priority scheduling
Peer-to-peer downloading	100 kbps-100 Mbps	Best effort

We discuss the various related literature under the following subheadings.

2.4.1 Fixed Line Technologies

Fixed line broadband access architectures are connection orientated and require a physical dedicated communication cable such as coaxial, twisted pair or fibre-optic cables for transmission. In an inaugural lecture held at the Technical University of Denmark (DTU) by Professor IdelfonsoTafur Monroy, the topic he was presenting was based on Optical Fibre Wireless Connectivity [10]. He mentioned that his goal of 100 Gbit/s wireless transmission will redefine the access of internet landscape in which users will achieve faster downloads of movies in Blu-ray or High Definition (HD) in a matter of seconds, a very fast way of accessing information [47]. Fibre-optic is a very thin piece of flexible glass smaller than a human's hair, encased in protective coding in which a laser beam is used to carry digital signals [8]. Optical broadband access is a type of physical medium that can carry several channels at once.

It has been stated that xDSL has disadvantages when it comes to distance, the connection is from a telephone switch station such as a plain old telephone service (POT) to a home or office usually the distance is less than 20 000 feet (ft) which is 6 096 meters (m) or 6.096 km. This causes the signal quality to decrease and the connection speed drops when the length from the user to the DSLAM increases [6]. The various forms of xDSL such as the ADSL,

SDSL, VDSL and ADSL2+ have services and distance transmission speed limitations that minimize the network coverage and also they do not meet the bandwidth requirements for HDTV also struggle to provide VoD applications [6].

After the various xDSL standards then there was a system called broadband power line (BPL) technology that allows data over the internet to be transmitted utilizing power lines using frequencies just from AM broadband (1.6 MHz) to the microwave region, BPL are cost effective because they can service a larger number of subscribers [6]. This architectures which include FTTB, FTTP, or FTTN use fibre optical broadband, where the fibre is brought to the buildings, premises and nodes and is being connected with other technologies to be distributed among the resident subscribers over copper cables or using wireless technologies [6]. Applications that have converged on the two solutions from the FTTH, the first is the PONs and secondly are the point-to-point (P2P) networks.

In the PON architecture the main signal is passively split and shared by between 16 and 35 subscribers using encryption and compress methods of subscriber traffic [6]. PON is very robust and is a maintainable broadband access; it can also be made more resilient to poor weather conditions and again is an energy efficient solution that can be improved on the energy back-up strategies [6, 8, 9]. This architecture is a fibre infrastructure where you share a single line interface in an optical line termination (OLT) at the central office by a passive split fibre network and it also allows 32 or even 64 subscribers to be connected in just one line interface via an optical network unit (ONU), the bandwidth on such a medium is a TDM scheme so one has a downstream in GPON; in most cases one will experience 2.5 Gbit/s downstream and 1.25 Gbit/s upstream in most file installation, while packet addresses are broadcast over a passive start [6].

FTTH are fully passive distribution networks over long distances without any active equipment because PON solutions have no outside-plant electronics.This reduces network complexity and economical costs whilst improving reliability and it can also provide high bit rates of around 10 or 100 Mb per subscriber [6]. Fibre in the PON is power efficient thanks to the fact that users are sharing a single line interface amongst multiple users, more efficient than P2P systems; FTTH is a best choice when replacing damaged optical fibre infrastructure [6, 9, 18]. This model can have resilience options GPON such as ONU redundancy and full redundancy; optical network have the ability to implement a sleep mode cycle during zero or less traffic but otherwise the GPON is fully functional in an awake/steady state. Privacy is ensured due to methods such as time shifting and personal encryption of each subscriber's

traffic [6]. There are actually two FTTH architectures which are as follows: the P2P and point to multipoint networks. In the P2P network a home is actually directly connected to a local exchange which is connected via a dedicated line connection to the national or mobile operator for each subscriber utilizing an optical fibre, there are no passive splitters and this solution is very demanding when coming to costs due to facts like uncontrolled installations and also reduced reliability just to mention a few.

In the Citizen newspaper of Friday the 25th of April 2014; in one of the articles, one of the leading mobile operators in South Africa MTN announced that it has launched a FTTH project and what is surprising is that even Vodacom is targeting the very same approach of doing the same project of FTTH rollout.In 2013 Vodacom intended to buy Neotel as part of delivering FTTH and FTTB for it to also participate in providing SA with optical broadband access. South African mobile operatorMTN has introduced an ultra-fast internet into a high-density residential site, Monaghan Farm, north of Johannesburg[48]. Monaghan farm which is 1260 acres (ac) or 5.099 square km (km^2) and about 60% of its residents have signed up for the services and MTN will commercially launch the fibre services on the 1st of June this year 2014. Both MTN and Vodacom want to buy Neotel a fixed line service. This means the future of SA is going in the right direction in terms of optical broadband access if one of these mobile operators cash in and buy Neotel the second national operator after Telkom this actually translates into an experience of fibre nationally.

EbenAlbertyn Chief Technology Officer of MTN SA told Duncan Alfreds of news24 that indeed SA is ready to experience optical fibre, and "… the current set of speeds on offer"[49]. In this FTTH solution you will be able to expect speeds of around 100Mbps similar to Telkom because Telkom offers speeds of 70, 80 and 90Mbps and recently Telkom Group CEO Sipho Maseko on the 23th January 2014 told the Talk Radio 702 "Telkom has developed and is currently running a similar project of FTTH pilots in places such as Rosebank, Bryanston, and the Waterkloof area in Pretoria"[50].

2.4.2   Multipoint Multichannel Distribution System (MMDS)

For a wide coverage area only MMDS are used. You can find such architectures in areas such as a metropolitan network and this architecture uses the following links: the P2P and the recent one which is a point-to-multipoint microwave links [6]. A P2P microwave link is a microwave system that requires a multitude of P2P links using NLOS whereby each transmitter is directly connected to the receiver via a dedicated link and this link allows

antenna systems utilized for microwave links to be replaced by a sector antenna in both the home or business and transmission base station [6, 8, 9]. Currently MMDS architectures use a point-to-multipoint microwave link to replace the old P2P link because of microwave link limitations. This solution is capable of transmitting signals to multiple locations within a 60°or 90° sector angles, sector antennas are made from aluminum and fibre glass to ensure absolute protection, no disturbance of signal failure and they can operate under bad weather conditions because it is DC grounded [6].

MMDS architectures deliver TV signals, telephone/fax signals and data communication signals. This strategy reduces cost per-link and is cost effective [6]. When using an LOS MMDS solution, it requires the use of a small digital receiver placed at their locations in line with the transmitter to avoid obstruction such as hills or mountain areas; and the distance between the receiver and transmitter is approximately 100 km, but the distance will be significantly less when the situation is otherwise, when the scenario is the one for LOS then the distance is greater than the scenario of NLOS [6]. The most advantageous thing about MMDS is that it offers channels of about 6 MHz wide and it can be accessed on both licensed and unlicensed bands, hence MMDS channels with higher bandwidth block of 200 MHz are only accessed by the subscribers the MMDS carries [6]. It also has something to offer such as 99 digital TV channels, over 10Mbps of data streaming and it is giving a total of 1Gbps in capacity in Ethernet connectivity [6].

Licensed frequencies enable the subscribers to be protected from any kind of interference such as rain, fog or snow and the total performance is not affected by a bit due to the fact that MMDS networks have replaced the old antenna infrastructures by the latest sector antennas used in the point-to-multipoint links [6]. However, this network has several disadvantages including the fact that it suffers from the ultimate limitation of limited number of licensed channels available, like we have mentioned above that only licensed channels experience a high bandwidth block because MMDS can render services to licensed and also to unlicensed bands, but under certain bandwidth [6].

Bandwidth required to easily allow and accommodate triple play services (voice, data and video) and on-demand applications is about 600 MHz but MMDS networks can offer bandwidth along this intervals of 2.1 to 2.7 GHz which is approximately equal to 2700 MHz if only there were enough licensed channels available; but this restricts the licensed MMDS subscribers because they can typically operate only the 200MHz which makes it difficult to

access the triple play services, this is due to the limitation on licensed channels available [6]. This disadvantage makes MMDS a broadband solution which is suitable for only low data rate or localized services which is clearly not a good and attractive approach, when we talk about the future of wireless broadband access, published in a white paper in [6].

2.4.3 Local Multipoint Distribution Service (LMDS)

There are other solutions in the wireless technology that are competing with MMDS. Unlike MMDS architectures LMDS only operate in very high frequencies called the ultra-high frequencies (UHF), radio frequencies, of approximately 27.5 to 31GHz which is equal to 31000 MHz with such statistics an individual can only wonder what is LMDS capable of? This means that it can render triple play services without any queries and this kind of UHF offers bandwidth the capabilities of doing everything possible in the future under wireless broadband accesses [6]. LMDS offers much higher bandwidth when compared to MMDS networks but they can both cover over a wide area network a metro network architecture using point-to-multipoint links but, both these wireless architectures the MMDS and LMDS offer a more economical solution which is a cost effective solution for metro network coverage [6]. It has a main disadvantage when coming to distance limitations because its radio signals can only be limited to approximately 8 km due to factors such as high free space attenuation caused by electromagnetic waves that would result from a LOS meaning there is a loss in signal strength [6]. This architecture will perfectly suit in a LAN due to the fact that LMDS have been implemented in the US, it can also act as a two-way broadband service and deliver triple play services [6].

2.4.4 Free Space Optics (FSO)

FSO enables even more ultra-fast transmission to transmit information at the speed of light, whilst in the light subject to the existence of a wireless technology that is super-fast that utilizes light propagations in free space to transmit data wirelessly while communications is connectionless between a transmitter and a receiver. It also has similar limitations when compared to other wireless technologies and its limitation is distance because it is limited to a distance of approximately 4km using infra-red and laser sources [6]. Data transmission rates are between 10Mbps and 1.25Gbps because this type of system only exists when there is clear LOS so that it can operate at the maximum speeds of THz frequencies and it does not emit RF signals to avoid signal attenuation and its beam is very tight [6]. This technology is

very economical when coming to installation; with very low cost due to the fact that there is no licensing of channels, hence FSO systems only utilize light instead of radio waves [6].

This network supports private applications; it can be a mobile and stationary terrestrial links, Overton mentioned that free space optics communications for terrestrial, space-borne, airborne, and waterborne applications will advance in light source and detected schemes which will extend data rates despite atmospheric challenges [6]. FSOC is the future heterogeneous communication network because it offers mobile networks, AP provider networks and private networks the use of satellite so that broadband access can be used nationally in the near future. This solution fully depends on LOS links. It also offers a very high bandwidth to sustain wireless communication links over a long distance but atmospheric challenges severely degrade the links' total performance [6]. In such architectures like this one we can have advantages such as long distance allowance, huge capacity, flexibility and security.

2.4.5 Wireless Fidelity (Wi-Fi)

In most cases, in the past, many users used to refer to any structure of wireless technology with coverage of wireless internet as Wi-Fi particularly within a local area. In a small geographical area WLAN where we have nodes that are connected to the internet using wireless Access Points (APs) and these nodes have established an active connection and there is some type of wireless communication using 2.5GHz UHF and 5GHz SHF radio waves, this activity is called the Wi-Fi technology [6, 8, 9, 18]. What firstly comes to mind when one hears of the term Wi-Fi, one will probably think of wireless APs emitting radio waves, that cover a small area that is within a few meters and the wireless AP are the devices that provide internet coverage. This type of network does not require LOS radio waves and Wi-Fi solutions do not consume too much energy because they can operate at averagely low power. It can go on to achieve distances that can range from 30 to 40 meters because at this range signals can penetrate any object and be transmitted from a Wi-Fi transmitter to the receiver in a NLOS WLAN [6].

The NWU (Mafikeng campus) is using Wi-Fi wireless AP to cover students, staff and guests with wireless internet connection; and this wireless AP cover very short distances around campus. The campus wireless network is based on two-step processes of security: the first step is authentication and the second step authorization. The university authentication grants students, guests and staff access to the network resources after ensuring that the user is who

she/he claims to be by the process of typing in your correct username and password before accessing the wireless broadband network. Authentication allows the NWU staff and students after logging in to access various applications that are trusted based on the user's identity. The staff and the students do not access the same resources and their network interface is different.

The NWU wireless network does not allow any user to access it; hence NWU-guest is for guests. The NWU-guest basically requires a password for authentication but the password changes from time-to-time and it changes on a weekly basis. This network is only available to guests, for an example if the guest visits the campus for whatever reasons and the guest wants to access the wireless network the user is then offered this type of network which is compatible to any node, it also accommodates smart phones. The NWU WIFI covers a radius of 100 m form the wireless AP.

In general Wi-Fi wireless AP connections can cover small areas in a WLAN, Wi-Fi internet coverage ranges from a radius of 30 m indoor and 450 m outdoor and the Wi-Fi network transmitters can operate using a low power within a low frequency [51]. The electronic gadget that uses Wi-Fi can easily handle and accommodate all multimedia content form referring to the triple play services; the reason being this technology uses UHF and SHF, in a point-to-multipoint fashion, you are free to say that Wi-Fi is an integration of LMDS wireless network in a small localized area and it is inherited form LMDS architectures. Wi-Fi technologies have encryption software for security reasons and software's that have the ability to detect virus and threats on the wireless network; meaning this technology is protected, it is safe and convenient to users [6].

The latest Wi-Fi products allow data rates of up to 54Mbps; what we like about Wi-Fi networks is the advantage of being able to update and upgrade to new integrated Wi-Fi products and Wi-Fi products are compatible to any smart node [6]. Lately Wi-Fi service providers are using multiple Wi-Fi transceivers to provide Wi-Fi connectivity to the users and private enterprises (e.g. Hotels) over a radius of approximately 3km, this is even implemented in cities such as the Dutch capital (Amsterdam), but this strategy has limitations on channel capacity practically this disadvantage on bandwidth only exposes the user to approximately 1Mbps of data rate rather than the usual 54Mbps [6].

"Project Isizwe rolls out a free Wi-Fi network architecture for the city of Tshwane in Pretoria, the project is part of the city's plan to embrace wireless broadband network technologies and

the project's phase one was successfully rolled out when free wireless internet the Wi-Fi network was provided to the public within a space of 5000 square meters (m^2), covering places such as the Church square, on the 26 November 2013 last year", said the city and the Project Isizwe founder and CEO Alan Knott-Craig [52].

2.4.6 Worldwide Interoperability for Microwave Access (WIMAX)

There is a recent upgraded Wi-Fi product called the WiMAX (IEEE 802.16), as described above, one of the advantages of Wi-Fi network products is that they can be upgraded into integrated Wi-Fi wireless network products that support QoS robustness. Since we planned to focus on implementing the hybrid architecture of the FiWi, the FTTW architecture which includes two domains, one of which will be the wireless network domain called the WiMAX, the new evolution of wireless networks because WiMAX is an integration of Wi-Fi networks covering wide geographical areas; and the other WWAN and it is inherited form Wi-Fi architectures; WiMAX support Wi-Fi devices. This wireless solution has encryption software for security reasons and software that have the ability to detect virus and threats on the wireless network [6].

The IEEE 802.16 technology is similar to Wi-Fi, but it is better because it covers a much greater distance when compared to Wi-Fi and it uses a point-to-multipoint last-kilometer broadband wireless access solution [6]. We have two types of WiMAX: the WiMAX that depend on LOS and other that does not rely on LOS but hence they utilize NLOS systems. In other instances the IEEE 802.16 that rely on LOS are referred to as P2P solutions hence point-to-multipoint systems that utilize NLOS are being offered by certain IEEE 802.16 solutions [6]. We dealt only with WiMAX wireless networks that use NLOS systems due to the fact that we wanted to achieve our main goal, since we are only focusing on architectures that rely on NLOS systems; the reason behind our approach is because these systems are being developed to offer large-scale consumer broadband services in full. It provides fixed nomadic (e.g. sector antennas), reliable and portable mobile wireless broadband connectivity with a base station within a given sector cell across cities and countries through a variety of nodes [6, 53].

Wireless broadband solutions like this one can be a backhaul to an optical fibre network from the ISP operator in a large geographical area. Lately wireless broadband is the backhaul of even the latest mobile network, the 5G. The latest Samsung phone, S5, is using 5G network. It also offers QoS and multicasting and it is directly capable of supporting triple play services

aiming to ultimately delivering capacities of approximately 75Mbps per channel for both fixed and portable access applications [6]. All these wireless solutions have various disadvantages. It may be the disadvantage of the coverage distance , bandwidth limitations, or security and cost constraints but the IEEE 802.16 standard have bandwidth limitations, with bandwidth that can be lower than the channel capacity since WiMAX is a shared bandwidth network that depends on the customer per-channel contention ratio [6]. WiMAX is a wireless broadband access technology that provides communication across wired and wireless connectivity [51].

NLOS IEEE 802.16 standard offers two installation possibilities; the indoor self-install and outdoor CPE and it also offers two grades of installations: standard and full-featured. NLOS ranges from 3 to 5 km carrying a maximum data rates of 2 to 10 Mbps, for fixed and portable access applications; and the delivering capacity is up to 75 Mbps per channel in a typical cell radius of 3 to 9 km [6]. For mobile networks within a typical cell radius deployed of up to 3 km and it provides up to 15 Mbps of capacity [6]. One disadvantage about the NLOS systems, especially the outdoor self-install one is that there is a severe reduction in the signal as there is attenuation caused by the infrastructure of the buildings, but they have simplicity of installation [6]. IEEE 802.16 standard is the next generation wireless broadband access network; but satellite architecture is so expensive to build when dealing with the cost constrains and they are limited to capacity per subscriber [6].

2.5. Levels of security concerning metro network architecture using hybrid broadband

The backhaul optical broadband access architectures PON, the powerful backbone faces several security challenges and it is vulnerable to a variety of attacks in the physical layer such as jamming or interference, physical infrastructure attacks, eavesdropping and interception [54]. The core important aspect is making sure that transmission taking place in optical fibre the uplink and downlink communication directions of this network is properly secured in which encryption, CDMA confidentiality, anti-jamming as well as optical steganography are utilized as various defense mechanisms against the security threats [54]. PON architectures do not suffer from interference and cross-talk when placed in a parallel or adjacent optical fibre infrastructure because interference reduces data rates. PONs do not generate electro-magnetic waves hence they are less vulnerable to eavesdropping. There exist security mechanisms at the physical layer to protect the content or the light beam that is used to carry digital data and this mechanism enables the access to broadband medium to operate at high speeds. Fibre cables do not corrode or rust [54]. PONhas the advantages of 1.25Gbps

of bandwidth, low loss, and low noise when compared to the coaxial cable plants and fibre plants require very little maintenance. DWDM-PON solutions share the large fibre bandwidth among many users in a large coverage area through a passive splitter [24].

2.6. Cost effective

Other authors from [19-21] mention that PON architectures based on OBS paradigms are inexpensive, readily available to end-users and bandwidth is available in large quantities. When combining the merits of optical switching paradigms and making these paradigms coexist to support QoS. Critical factors affecting the design and deployment of next generation PONs in metro network architecture are eliminated by reducing the large number of wavelength converters and FDLs in an optical broadband network without affecting the overall performance. Optical wavelength converters and FDLs are very expensive in maintenance and in cost constraints[22].

Next generation PON architectures are cost-effective when coming to communication costs. There are challenges of cost encountered when considering high bandwidth and transmission rates but, in our favour, the hybrid broadband architecture (FTTW, FiWi) is within the good market bounds, is cost effective due to its point-to-multipoint and it uses broadband transmission mediums when compared to normal broadband standards (e.g. copper wire, coaxial cable/wire and fibre optic). Another challenge when it comes to cost, we highly considered maintenance and durability so recommendations were based on a hybrid broadband architecture. Converging the two access domains to create a single network; rather than two separated network architectures since they both offer QoS broadband access, it is a cost-effective innovation. The QoS hybrid broadband access solution is a brilliant idea and very inexpensive system maintenance. QoS Broadband is better than using baseband.

What national and mobile network operators do is that only subscribers can utilize and access the metro network architecture to ensure their commercial profits, but on the other hand the national and mobile network operators reduce costs so that end-users and subscribers can avoid paying highly abnormal prices. In the city of Tshwane many people can access free internet, thanks to projects like Isizwe that provide free Wi-Fi for people of Tshwane. The South African government is embarking on a very innovative project by subsidizing free internet broadband access in various communities that are financially disadvantaged, so that the main goal of providing free internet nationally becomes a reality. WiMAX solutions reduce cost hence they do not require the utilization of restricted hotspots. The mobile

network operator MTN and Isizwe projects are rolling out projects of delivering and making sure that people of SA will have internet in the future; whilst MTN is deploying high-speed FTTH technology that is capable of 100 Mbps in places such as high-density urban areas in Johannesburg and free Wi-Fi initiative by Isizwe of connecting the residents to the internet is currently alive in SA communities such as places like Atlantis in the Western Cape.

2.7. QoS support

Real time applications require QoS (e.g. voice packets in the broadband network). QoS is utilized to prioritize one type of network traffic over another and makes sure that it gets priority treatment across the network. QoS scheduling algorithms divide network traffic into classes (e.g. class A is allocated to voice and class B is allocated to video), it classifies the network traffic by differentiating the traffic from the other types of traffic that occur in the network. The best-effort and default queuing methods were originally designed to handle the internet network traffic. These scheduling algorithms are being replaced by the QoS scheduling algorithm.

QoS support broadband access architectures in a cost-effective and energy-efficient manner and can double and improve the performance of broadband access architectures to provide huge amount of Gbps of data rates with high availability and reliability [40]. QoS architectures are used to converge and facilitate optical fibre and wireless communication mobility using QoS requirements on the broadband network, focusing on the network throughput and transmission delay [36]. The major challenge was provisioning diverse services in the hybrid network hence in the internet of today the broadband network architecture are on the pursuit of QoS provisioning, different services are specified according to the type of network traffic [36].

We implemented the use of a scheduling algorithm called the priority scheduling in the hybrid broadband access architecture and this QoS scheduling algorithm provides the ability to give services in the network traffic that are higher in precedence, a better performance when compared to a network traffic with no priority. QoS priority scheduling is effective specifically for real-time triple play services [41]. Hybrid broadband access architecture uses both uplink and downlink transmission directions in a point-to-multipoint system in which QoS (e.g. priority scheduling) looks at the scheduling time slots to transport traffic with special delay requirements efficiently utilizing the bandwidth within the system, given a specific traffic priority [41].

QoS is the central objective in the access segment (e.g. architecture or mediums that are utilized in-between the central office and the user or nodes) of our hybrid broadband access architecture. Existing architectures in the access segment deliver poor QoS support, meaning the access segment has several challenges because many users of the internet network cannot enjoy QoS performance from online or on-demand applications. Our aim is to improve the performance of broadband access in the access segment because as the internet evolves, the architectures must also evolve to accommodate internet applications by including the QoS requirements to provide satisfactory service delivery to end-users and also to manage network resources [55]. IEEE 802.16e (WWAN) uses a QoS framework that is based on SFs and this particular framework is good in air interface scheduler [55].

FIFO, PQ and WFQ are controlling mechanisms in the network traffic, also known as three different queuing disciplines and these techniques control transmission movements of packets in the network routers [56, 57]. Queuing disciplines provide bandwidth allocation to both real-time and non-real-time traffic because end-users are currently dependent on triple play services like VOIP, video conferencing and file transfer but now a day network routers are merging FIFO, PQ and WFQ to work together and govern how packets are buffered while waiting to be transmitted [57, 58]. Queuing disciplines in the broadband access must co-exist as a single mechanism or technique to support QoS and maintain network traffic efficiently. Many authors [56-58] have highlighted that WFQ technique has a superior quality when compared to other techniques shown and proven by simulation results obtained from OPNET, analytically looking at traffic dropped, traffic received and packet end-to-end delay.

2.8. Previous Work

The results obtained in [14]were carried out using Net Cracker professional software. The tool measured, analyzed and evaluated the throughput, latency and packet loss of the DWDM-PON model. The results showed high transmission rates over long distances and proved low cost in deploying the network. The DWDM-PON model provided high throughput, low latency and low packet drop. Hybridizing optical fibre with a wireless system offers advantages of large bandwidth and low attenuations [57]. Radio-on-Fibre (RoF) architectures have reached high transmission rates over long distances and optical wireless network facilities are cost effective[59]. Proposed technologies for optical wireless integrations such as RoF access networks lack QoS capabilities [33]. Optical Burst Switching (OBS) was evaluated using a different simulation tool to enhance the QoS for high priority real-time traffic over next generation optical infrastructures[23]. OBS ensures the fairness of

traffic when transmitting packets over a network using weighted fair queuing (WFQ) which prioritizes traffic and supports QoS parameters. FiWi networks to enhance the facility of long haul network coverage transmissions using full duplex data transmission have been proposed [7]. FiWi architectures hybridize various optical networks with wireless networks. A similar study conducted by [12]presented the application of QoS in DWDM technologies. A DWDM model was duplicated into two scenarios namely: network with QoS and without QoS services. These services were measured using QoS parameters utilizing OPNET simulation tool [12]. Results in [38] show WiMAX access network supports QoS parameters.

2.9. Chapter Summary

In this chapter we have presented an overview of a hybrid (FiWi) metro network architecture requirements and design constraints; we also considered critical points and reviewed work done by other researchers. We mainly focused on areas such as optical and WiMAX network architectures, FiWi network architecture offers a great innovation of the highest QoS broadband access as far as convergence is concerned.

CHAPTER THREE
EXPERIMENTAL DESIGN

3.1 Chapter Overview

This Chapter describes in detail the method and simulation tool employed to archive our research goal. This experimental design focuses on simulation aspects of QoS parameters in FiWi on a network with QoS and without QoS, utilizing OPNET modeler version 14.5.

We focused on QoS of the hybrid architecture with the following access domains: the wireless broadband access domain WiMAX and the optical fibre backbone broadband access domain (DWDM-PON)[6, 36, 51, 60, 61]. The FiWi will cover a large geographical area enabling internet coverage and establishing wireless connections, thus, allowing any node to be connected either in a mobile or fixed position. We are converging DWDM-PON and WiMAX architectures so that these two network domains can offer internet coverage on a large-scale; North-West province [1, 8, 60].

Figure 3.1 shows the prototype that rolls out internet coverage on a large geographical area, the metro network architecture (e.g. North-West province). The conceptual model is hybrid FiWi broadband access architecture providing both rural and urban areas with unlimited QoS broadband network. We used a dedicated broadband access optical fibre that connects all the subnets. The optical fibre from the ISP network provider (e.g. Telkom) of metro network architecture connects four subnets and the passive splitter, splits and attaches the optical broadband to all four subnets because of a point-to-multipoint system. Since the passive splitter, splits the main signal from the ISP network operator such that the signal is shared by between 16 and 32 subscriber's traffic. In Figure3.1 the main signal will be shared by only four subnets that use WWAN in a metro network architecture [51].

In the Figure 3.1, we have the ISP network operator that splits the main signal using passive splitters, so that the internet signal can be transmitted to the subnets such as subnet a, b, c and d. For the broadband network to transverse any architecture, the architecture needs devices and mediums that can accommodate and carry QoS broadband access signals from one subnet to another, so the medium used is an optical fibre that stretches from the ISP network operator to the subnets in the North West province.
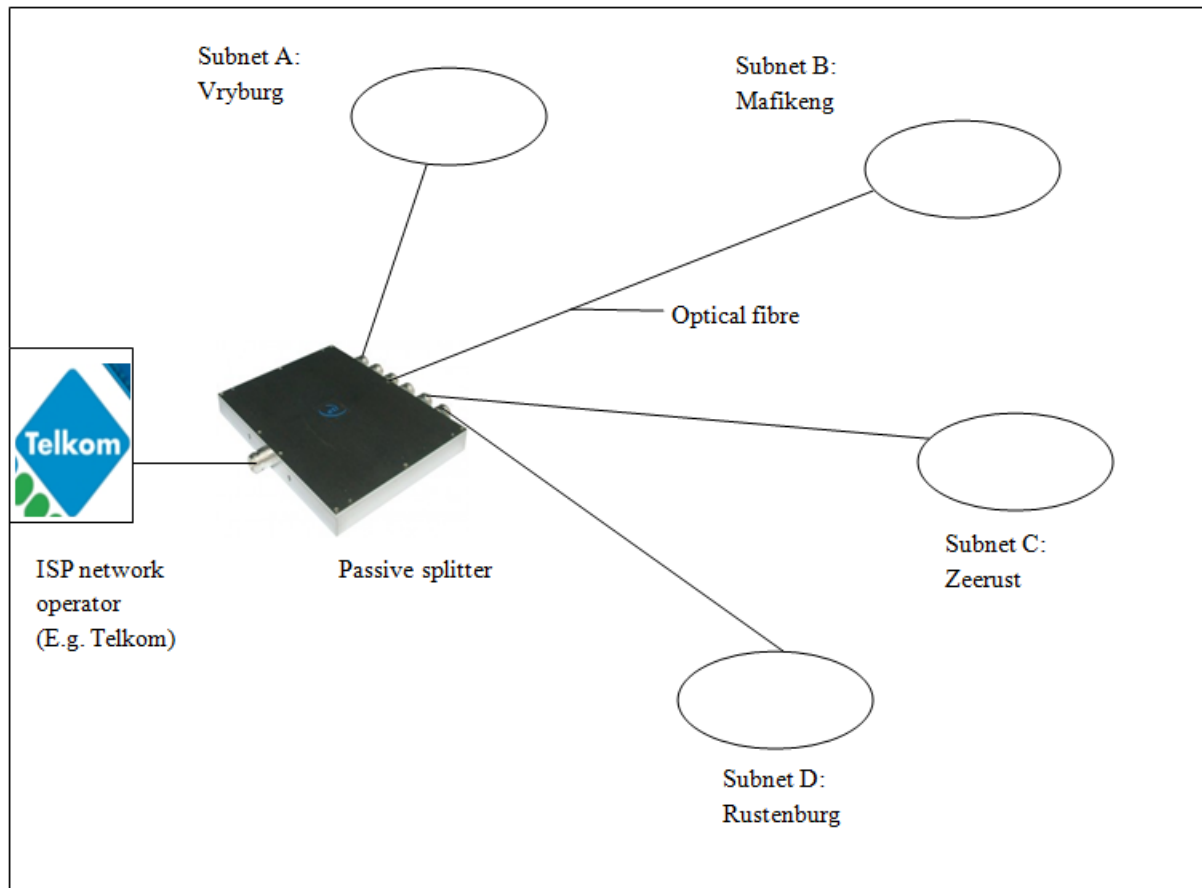
Figure 3. 1: Metro network architecture (North-West Province) [4, 21, 29, 30].

In Figure3.2 we focused on the WWAN in various local areas or cities such as Mmabatho, Magogoe and Danville. The business and home environment utilizes sector antennas as wireless APs to access broadband wireless internet and the WiMAX typically covers distances of approximately 50 km LOS but otherwise it covers less distances of 10 km NLOS [51]. WiMAX offers high QoS because this broadband network has the ability to allow fixed and mobile usage across a range of applications[51]. The hybrid FiWi architecture has been designed to be a cost-effective architecture that transports broadband internet access over a large-scale.
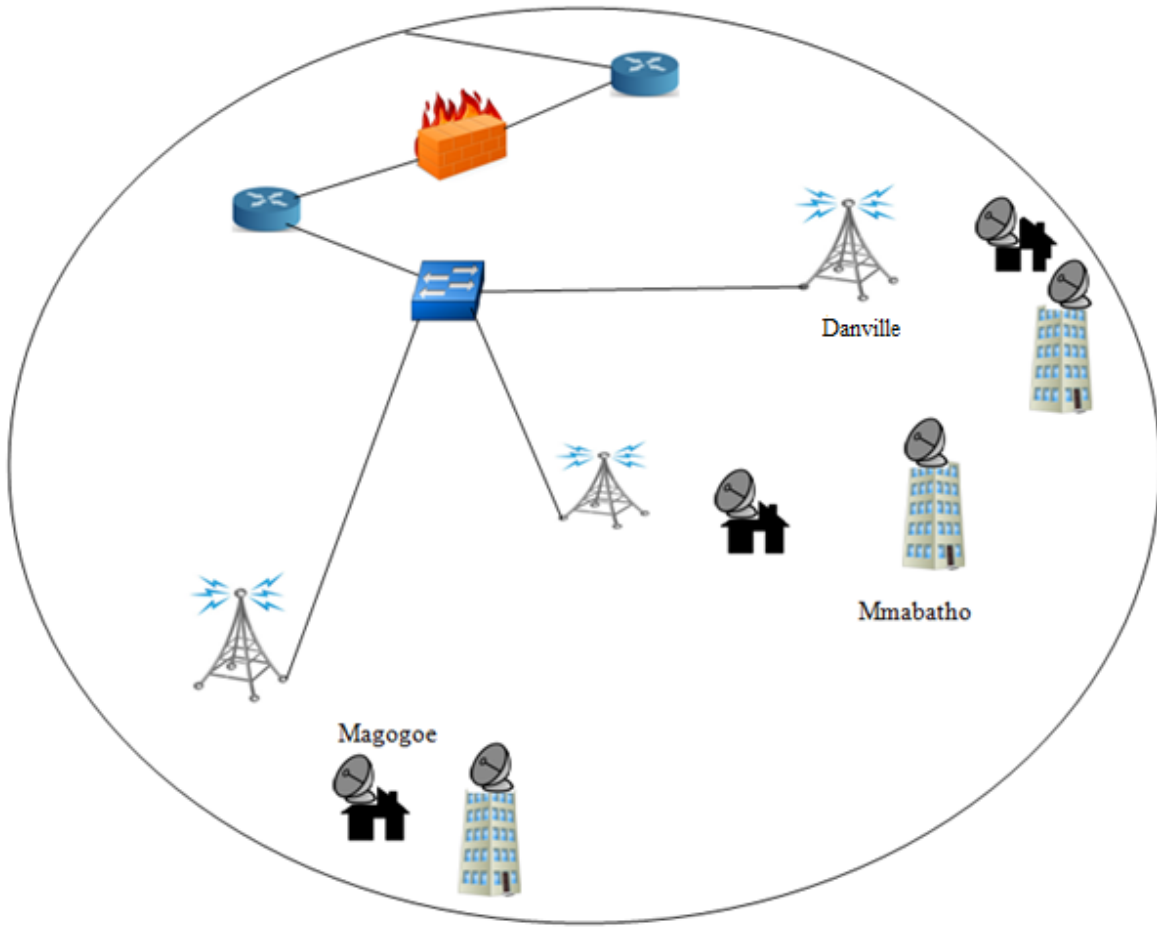
Figure 3. 2: Subnet B (Mafikeng) WWAN [4, 10, 21, 29, 30].

Figure 3.3 uses two WiMAX solutions: the fixed and mobile WiMAX architectures. The fixed WiMAX is the fixed backbone network that delivers wireless connections to the WWAN.The mobile WiMAX implementation transmits wireless broadband network to portable and mobile nodes that are within range in the city of Mmabatho. This technology gives the same output to all connected services including cellular networks [51]. The QoS integrates the wide geographical area, and it offers applications such as on-demand service, streaming media service and the triple play services [51]. Since we are using both the LOS and NLOS WiMAX; the point-to-multipoint system instead of a P2P system is to decrease levels of cost and the main reason why we are implementing WiMAX architecture is because WiMAX solutions are a backhaul to Wi-Fi wireless APs. Our architecture will house Wi-Fi wireless APs in small areas especially indoor, self-install buildings and near or close to the

parks and local resting places hence for outdoor CPE we will be using NLOS WiMAX broadband network architectures.
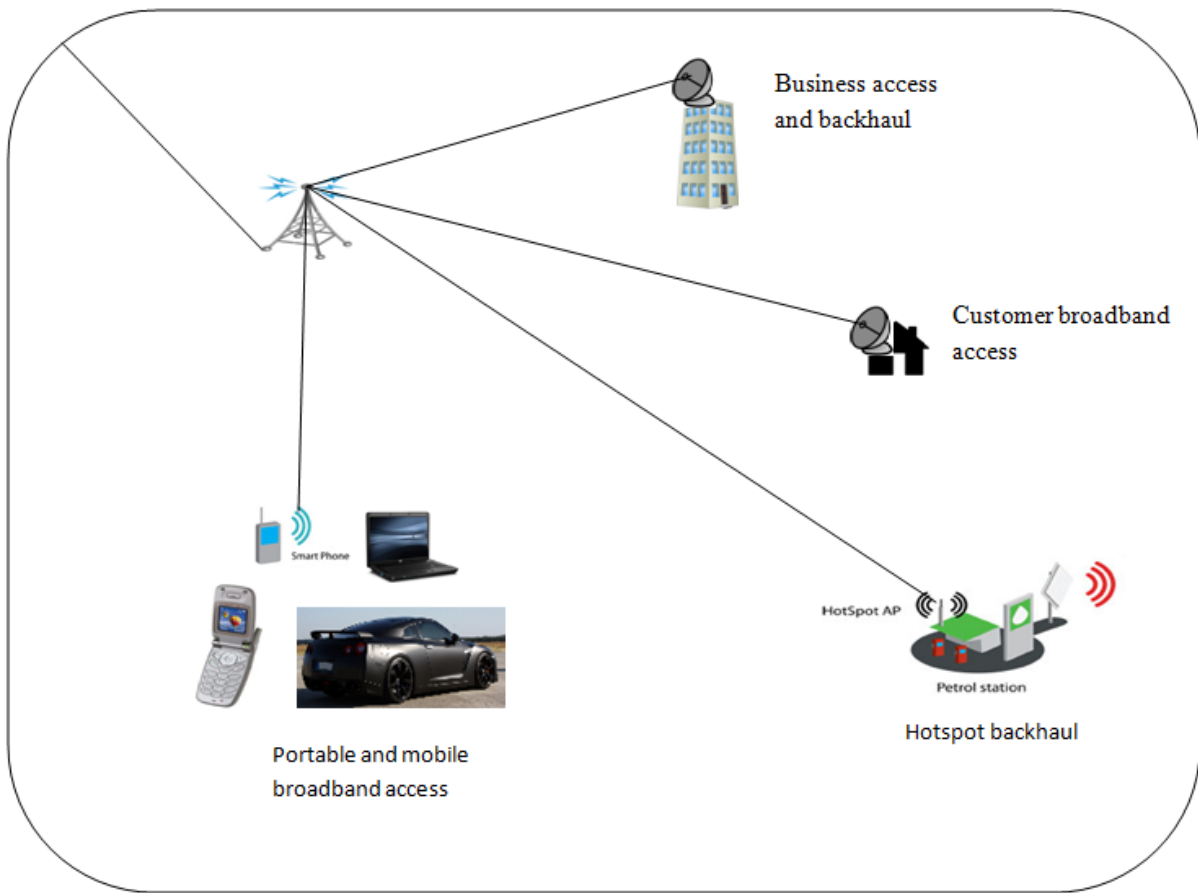

Figure 3. 3: Wireless business, home and hotspot backhaul environment (Mmabatho) [10].

All these Figures shown here in Chapter 3 display the convergence of the two broadband domain networks. From the mentioned scenarios we can now say that this metro network architecture is compatible to any node and network. The hybrid FTTW technologist complies with strategies of achieving a cost-effective architecture; it also supports QoS in offering various on-demand applications for both real-time and non-real-time traffic.

3.2 Simulation Analysis

We used simulation for performance analysis to predict how the network would behave in real life. This means a real-world network can be built in a node program as a prototype for simulation purposes [62, 63]. Based on these results, decisions can be drawn prior to implementing a network scenario in real life. The OPNET modeler has tools such as programming environment, network traffic selection, statistical data representation and projection, in order to make sure the perfect results are generated.

We chose OPNET modeler for the following reasons:

1. An OPNET modeler suite comprises protocols, multimedia applications and processes of the nodes in the overall network. It models all network types (including VoIP, TCP, OSPFv3, IPv6). One can test and demonstrate technology design in realistic scenarios. The main characteristics of OPNET as a tool are: accuracy, speed, ease of use and cost effectiveness [62].

2. OPNET modeler prides itself as the fastest discrete event-simulation engine currently on the market as compared to other simulation software tools such as OMNET and NS2. It is one of the most powerful simulation software packets. Network simulators were used in the past as performance, management and prediction tools, however, currently they are used mainly as network management tools and provide performance analysis and packet level analysis[63].

OPNET is based on C and C++ programming languages. It simulates fixed, mobile and satellite networks. It can be viewed as a high level network operating at packet level analysis [62, 63].

OPNET has a hierarchical structure that describes various aspects of the complete network being simulated. This tool provides domains to develop a representation of a system being modeled, organized in a hierarchical fashion. Modeling in OPNET is divided into three main domains, namely the network, the node and the process domains.

1. **Network domains:** These are network topologies or geographical scenarios showing coordinates and mobility. A network domain (Figure 3.4) specifies the overall scope of the system to be simulated using a high level description. It specifies the object placed in the project workspace in the system as well as their physical location, interconnection and configurations. One can view a subnet within a network or sub-network that consists of network nodes [12].
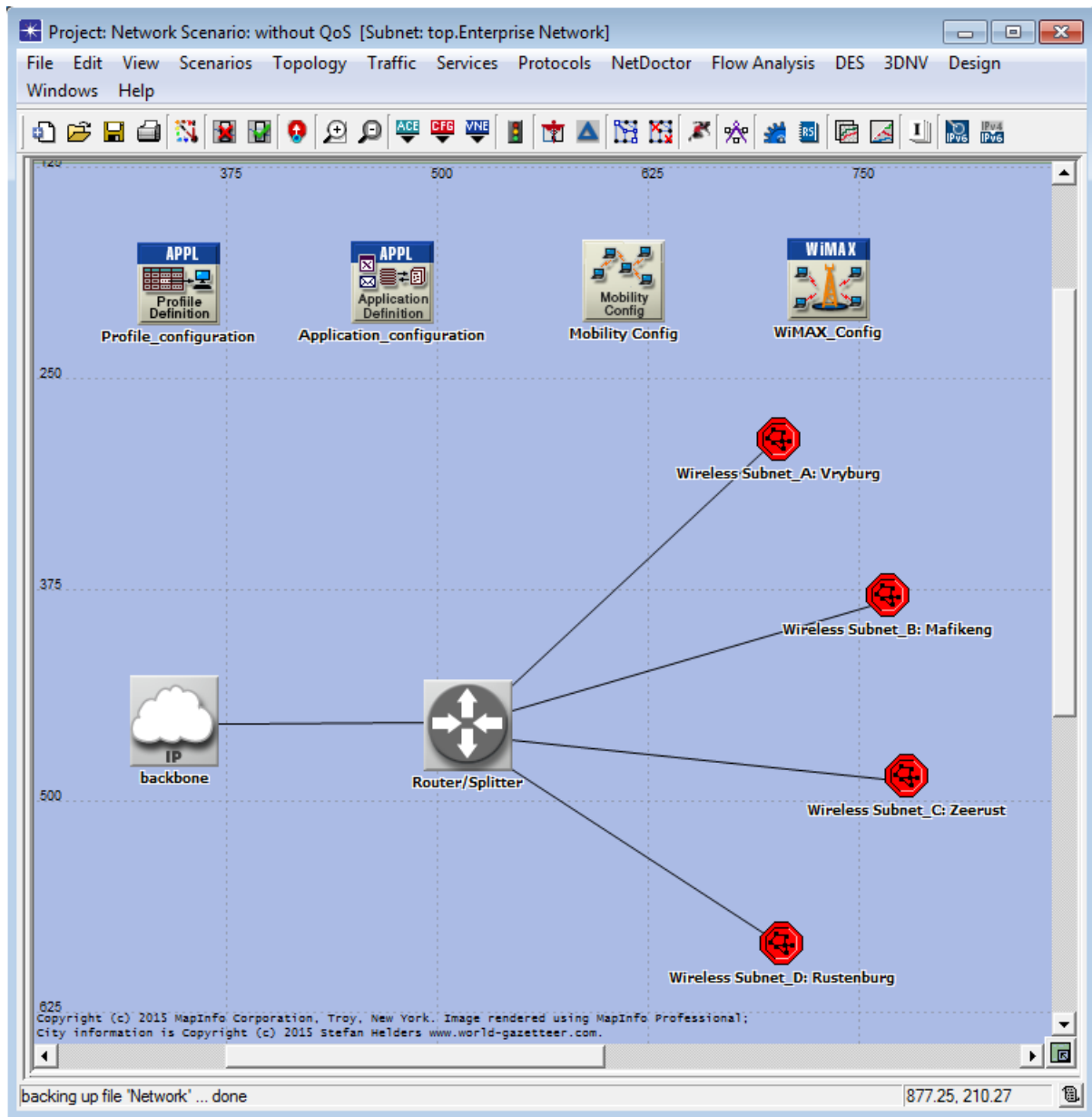
Figure 3. 4: Network domain[12].

2. **Node domain:** Figure 3.5 depicts single network nodes such as routers, workstations, switches and others. The nodes are connected by packet streams (red and blue streams), and provides the structure for the process models (see Figure 3.6). The node domain mainly specifies the internal structure of a network node as either fixed, mobile or satellite type including workstations, packet switches, satellite terminals and remote sensors[62].
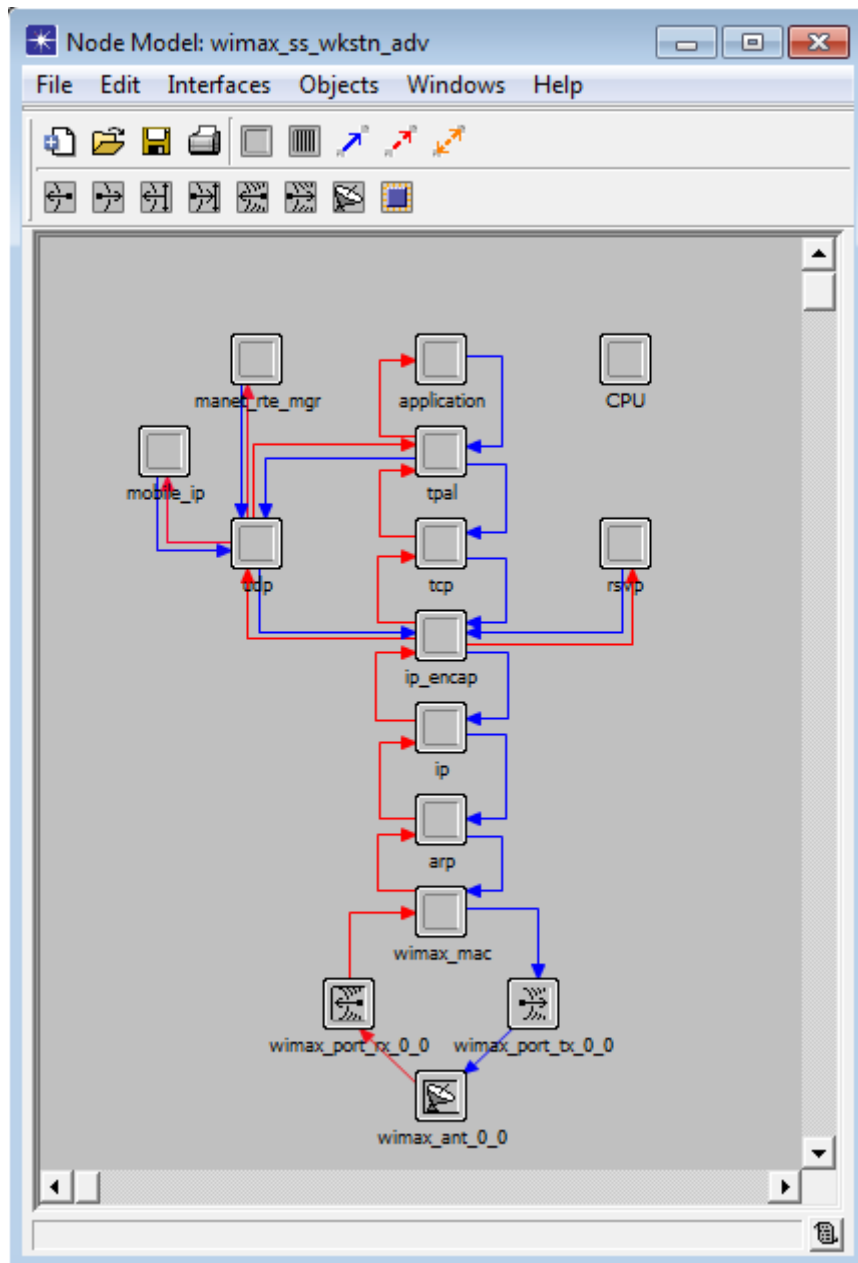
Figure 3. 5: Node domain[62].

3. **Process domain:** these are single modules and source code found within network nodes for example data traffic source model. This is the domain in which a researcher or developer specifies the various attributes and behaviour of the processor and queue models. It is depicted in Figure 3.3 [62, 63].
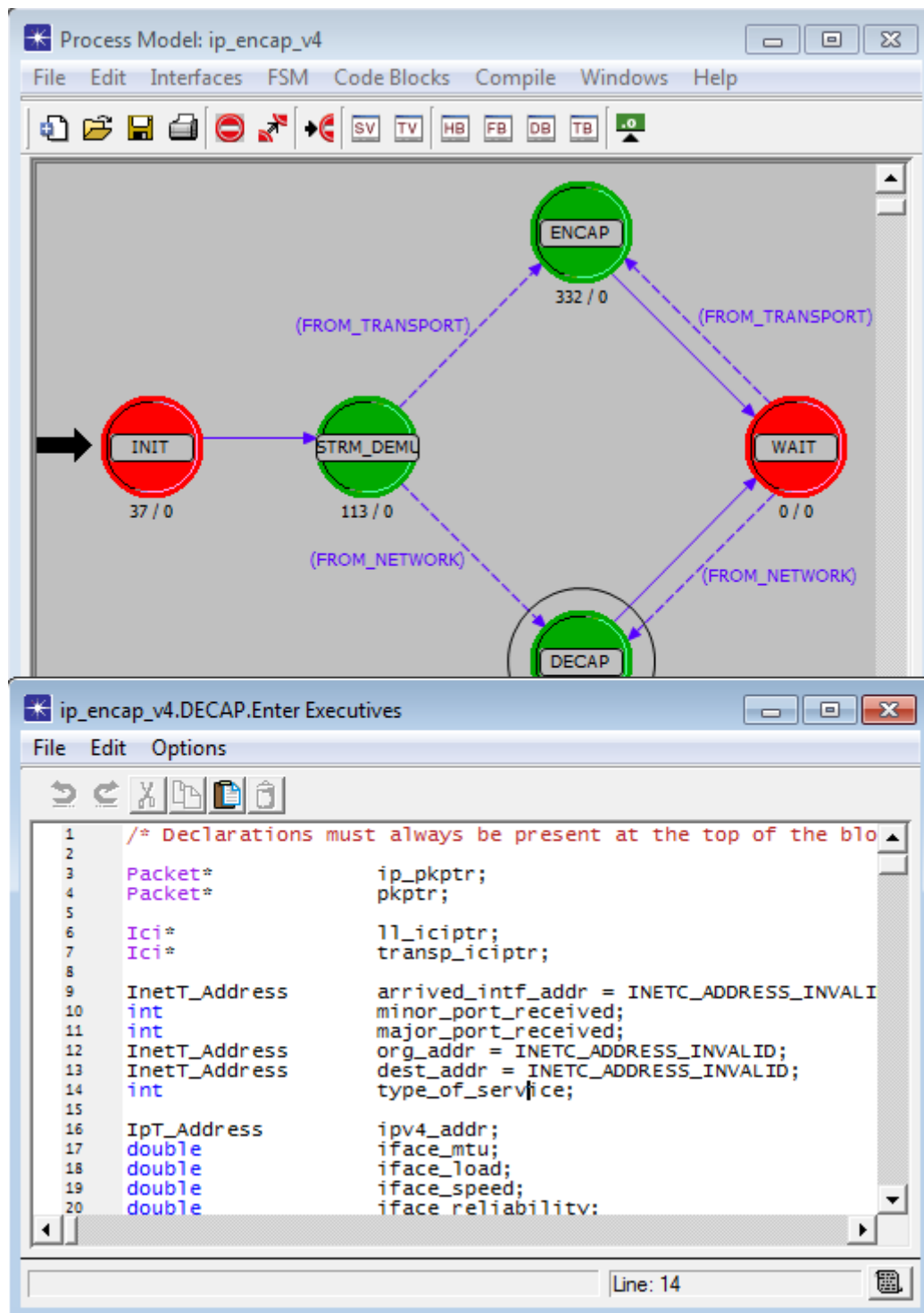
Figure 3. 6: Process domain[62, 63].

OPNET has a series of procedures which are very specific steps or phases that govern researchers and developers embarking on simulating a network. Figure 3.7 indicates the steps followed.
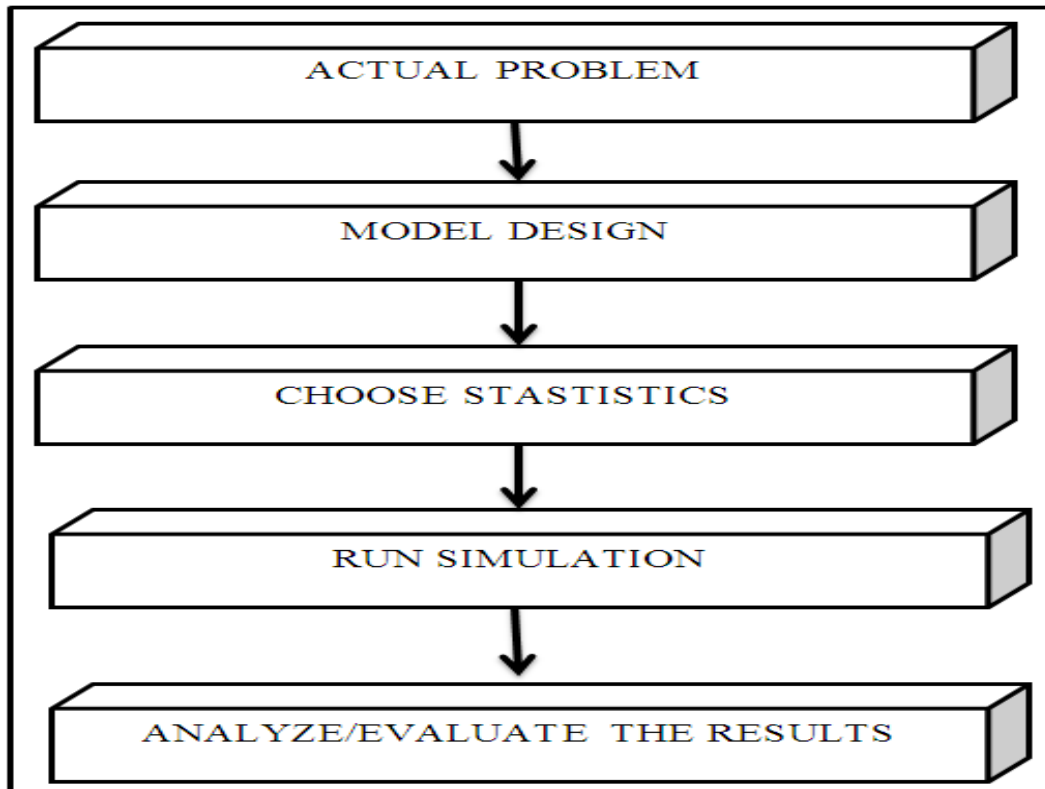
Figure 3. 7: The Five OPNET Simulation Design Steps [12, 62, 63].

3.3 Simulation Setup

The scenarios used in this simulation are based on evaluating the network with QoS and network without QoS, based on the http environment during heavy browsing. The two scenarios will be discussed in detail. Based on the packet delay variation, end-to-end delay, traffic sent, traffic received and packet loss the two shall be evaluated. This will help or contribute towards evaluating the two scenarios. Network without QoS was duplicated in order to implement the two scenarios namely the network with QoS and network without QoS. The http application was configured to generate the main traffic for the experiment.

Figures 3.8 and Figure 3.12 represented the network scenarios. The two scenarios are the focus of this research. Figure 3.8 represents the network with QoS and Figure 3.12 represents a network without QoS. The difference between Figure 3.8 and Figure 3.12 is the present of QoS parameters. The QoS parameters contain the setting for Figure 3.8 that are absent in Figure 3.12 and it is used to configure all the quality attributes of the network.

Two Experimental beds were setup as a network with QoS and another network without QoS using http heavy browsing.

3.3.1   Network with QoS

Figure 3.8 illustrates a network with QoS. Network without QoS (Figure 3.12) was duplicated and the duplicated model added QoS configuration. QoS is shown by the red colour in the QoS configuration tool. We chose to implement Weighted Fair Queuing (WFQ) instead of other queuing disciplines to prioritize traffic. The QoS network guarantees high bandwidth to improve triple play services and reduces access link bottlenecks. This network can satisfy multiple applications and runs concurrent processes. The QoS configuration tool invokes QoS parameters. QoS is measured and evaluated using the following QoS parameters: delay, jitter, bandwidth, packet loss and throughput. The FiWi architecture offers large bandwidths that are required to perform the transmission of dense services that users demand. QoS does not actually increase bandwidth but it prioritizes traffic to reduce traffic congestion over a network [62, 63].

Achieving QoS is the central objective of this research. To achieve this goal we designed a metro network that integrates optical-wireless access network to offer triple play services (video, voice and data) [64].
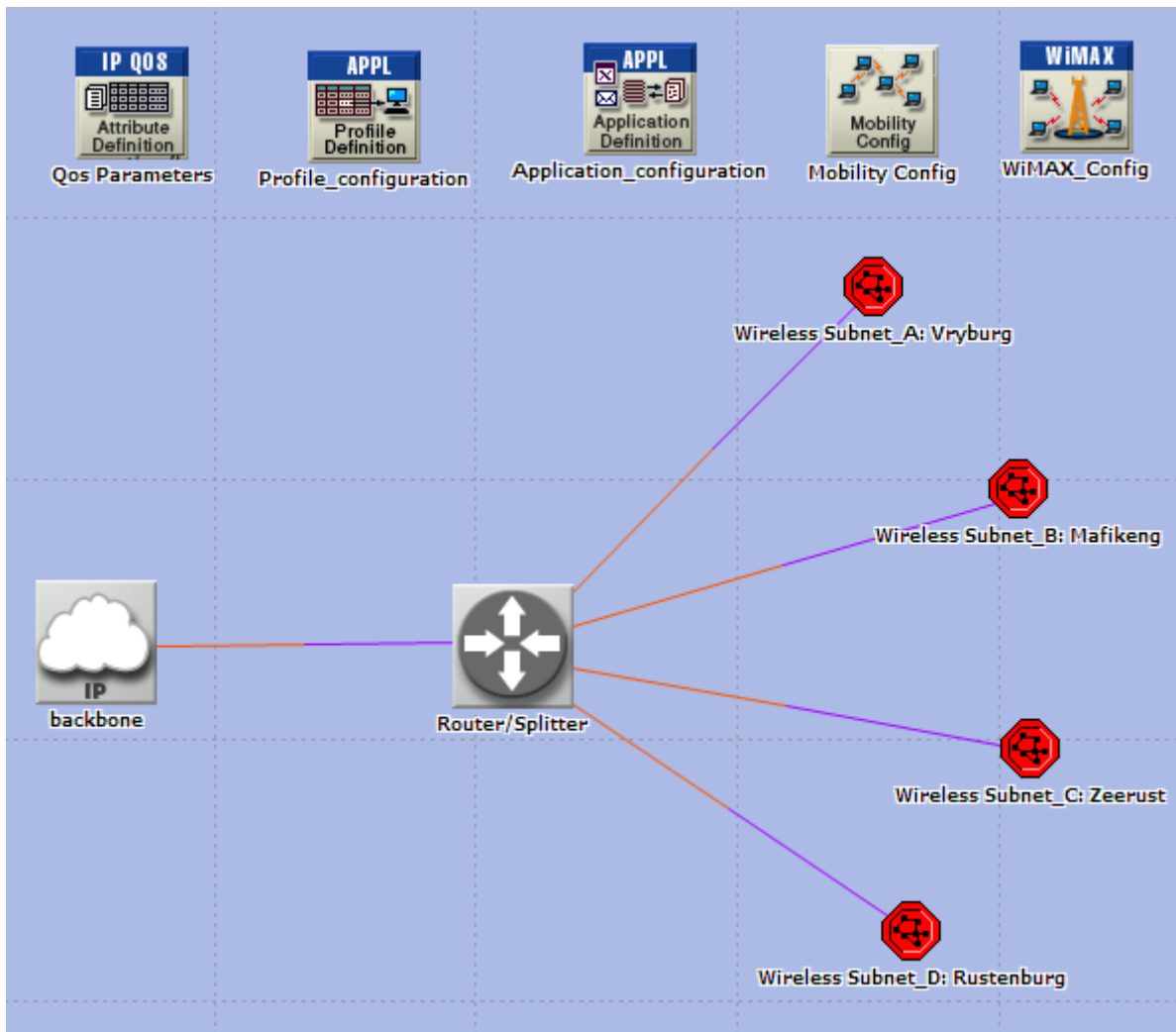
Figure 3. 8: Network with QoS.

OPNET utilizes the following queuing disciplines first-in, first out (FIFO), priority queuing (PQ) and weighted fair queuing (WFQ). Each queuing discipline constitutes a network scenario and QoS scenarios were studied under each discipline. A brief description of each queuing discipline follows.

FIFO (First-In, First-Out) Queuing

FIFO is the simplest of the queuing method but it is time consuming because packets will wait for a long time queuing to enter the buffer for them to be transmitted. Moreover, each queue has limited reserved bandwidth. FIFO algorithms transmit packets after receiving and queuing them. The first packet to arrive will be transmitted in that order regardless of the utilization and importance of the packet [65]. Figure 3.9 is an example of FIFO queuing. Packet_1 and Packet_2 represent voice and data respectively. Packet_3 represent video and

among these services there is no priority. If Packet_3 comes before Packet_1 then Packet_3 will be transmitted first because it reached the waiting area first.
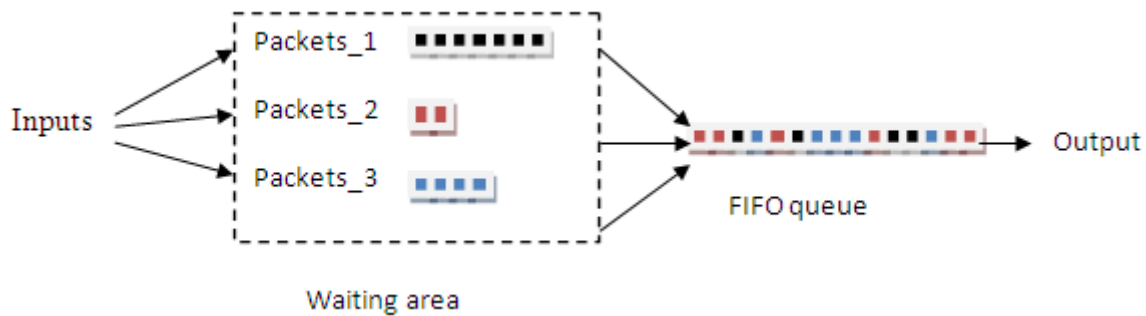

Figure 3. 9: FIFO (First-In, First-Out) queuing[65].

Priority Queuing

PQ transmits packets with low latency e.g. VoIP. This type of queuing discipline is time, loss and jitter sensitive and it processes critical data. This queuing discipline sorts packets in the buffer according to distinction priority which highlights the importance and urgency required in the transmission of packets. PQ is made-up of several important buffers separated according to classification. Figure 3.10 shows that incoming packets are classified by different priority levels. Packets are placed into the appropriate waiting queue where these packets are defined by length and priority. Incoming packets are triple play services. Voice is classified in a high packet queue because voice is a real-time application and it requires priority. Video occupies the medium packet queue while data is classified to the normal queue. Whenever, the router is available to send the next packet, it looks firstly to the high packets. If high packets queue is empty then the medium, normal or low packets can be sent. PQ are non-preemptive[29, 65].
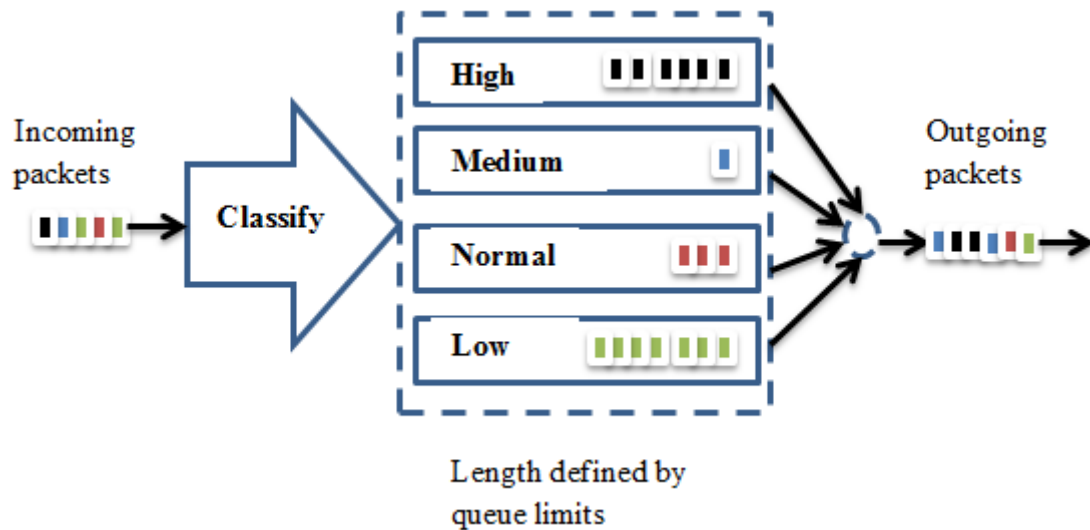
Figure 3. 10: Diagram showing example of PQ [29, 65].

WFQ (Weighted fair Queuing)

WFQ was used to invoke QoS parameters. We chose to implement WFQ because it is the most powerful building block for QoS. It factors weight to assign to each packet. Packets with higher weight are given more bandwidth. Its main advantage is that it prioritizes and protects packets. However, it has disadvantages in that, in most cases it finds it difficult to implement high speed network traffic for many concurrent processes. This is due to the fact that it needs to assign weights before the packets are delivered. Congestion avoidance mechanisms such as WRED (Weighted Random Early Detection) are implemented in this queue [29, 65, 66]. Instead of equal sharing, the packets are assigned to different classes according to size, bandwidth and priority in Figure 3.11. W1 is the queue for Real-time packets. Whenever W1 is empty the round-robin systems applies to W2 and W3 if they have the same size. Otherwise W2 and W3 use FIFO. We chose WFQ because it encompasses the merits of other queuing disciplines.
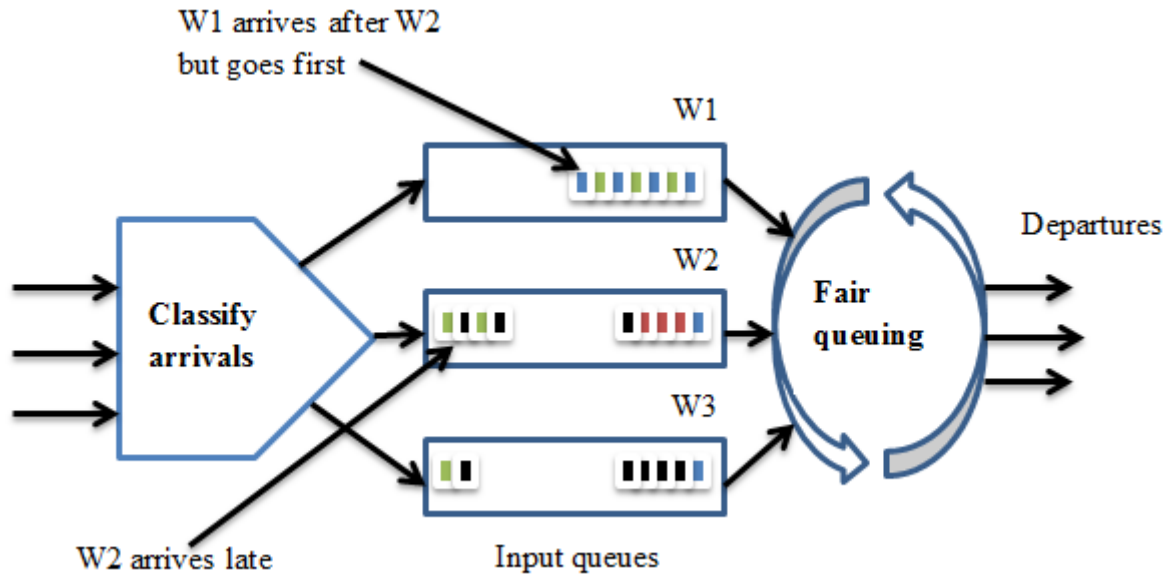
48

Figure 3. 11: Diagram showing example of WFQ [66].

3.3.2 Network without QoS

Figure 3.12 illustrates a network without QoS. We chose optical Burst Switching (OBS) to ensure the fairness of traffic when transmitting packets over a network [23]. OBS networks aim to improve the use of optical networks resources by providing unlimited bandwidth capacity and easier interconnection to other existing WDM networks [18, 19]. It assembles the packets that have the same constraints making a burst scenario and the burst is assigned to a wavelength channel before the burst is disassembled back into original packets routed to their respective destinations. This network uses First-In, First-Out (FIFO) routers and when there is a delay and loss of packets the quality of the network drops. Traditional network architectures used Best Effort (BE) services. These services caused traffic congestion over the network. BE services do not provide mechanisms that retransmit corrupt or lost packets and has no guarantee of bandwidth. Without QoS it is difficult for the network to transmit real-time applications because low latency is needed. QoS alternatives such as over-provisioning approach do not guarantee throughput and bandwidth and this approach is not cost-effective due to allocating high capacity.
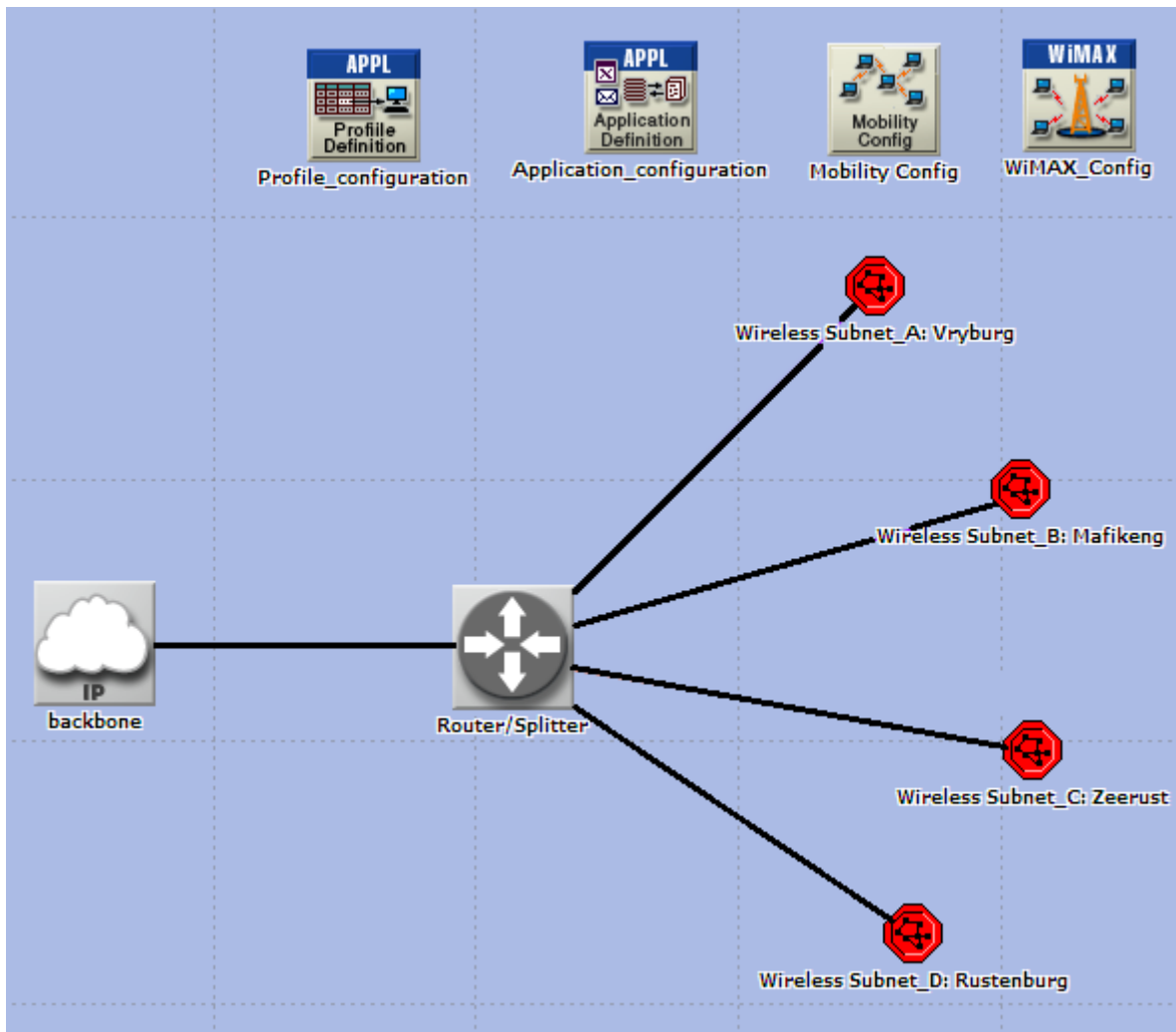
Figure 3. 12: Network without QoS.

3.4 Network Configuration

The adaptation figures 3.13 and 3.14 show the topology of the simulation setup. These figures will be duplicated in order to implement the two scenarios: network with QoS and network without QoS. Both topologies are made up of various devices and different configuration utilities:

1. IP backbone is used as an ISP (e.g. Telkom, Vodacom and MTN) for internet connectivity
2. The router/splitter in the middle is connected to both the ISP backbone and the main routers from each of the four wireless subnets using the PPP-adv link.
3. The broadband network with QoS coming from the ISP backbone is split by the router/splitter (ethernet4_slip8_gtwy) to each of the wireless subnets.

4. Four wireless subnets, each with a given number of mobile workstations, fixed base stations and http heavy browsing server runs WFQ with expedited forwarding service

5. In the subnets each router connects to the Ethernet firewall for security purposes. The routers, servers and firewalls are connected by the PPP-adv (Point-to-Point Protocol-advanced) link to transmit and receive packets.
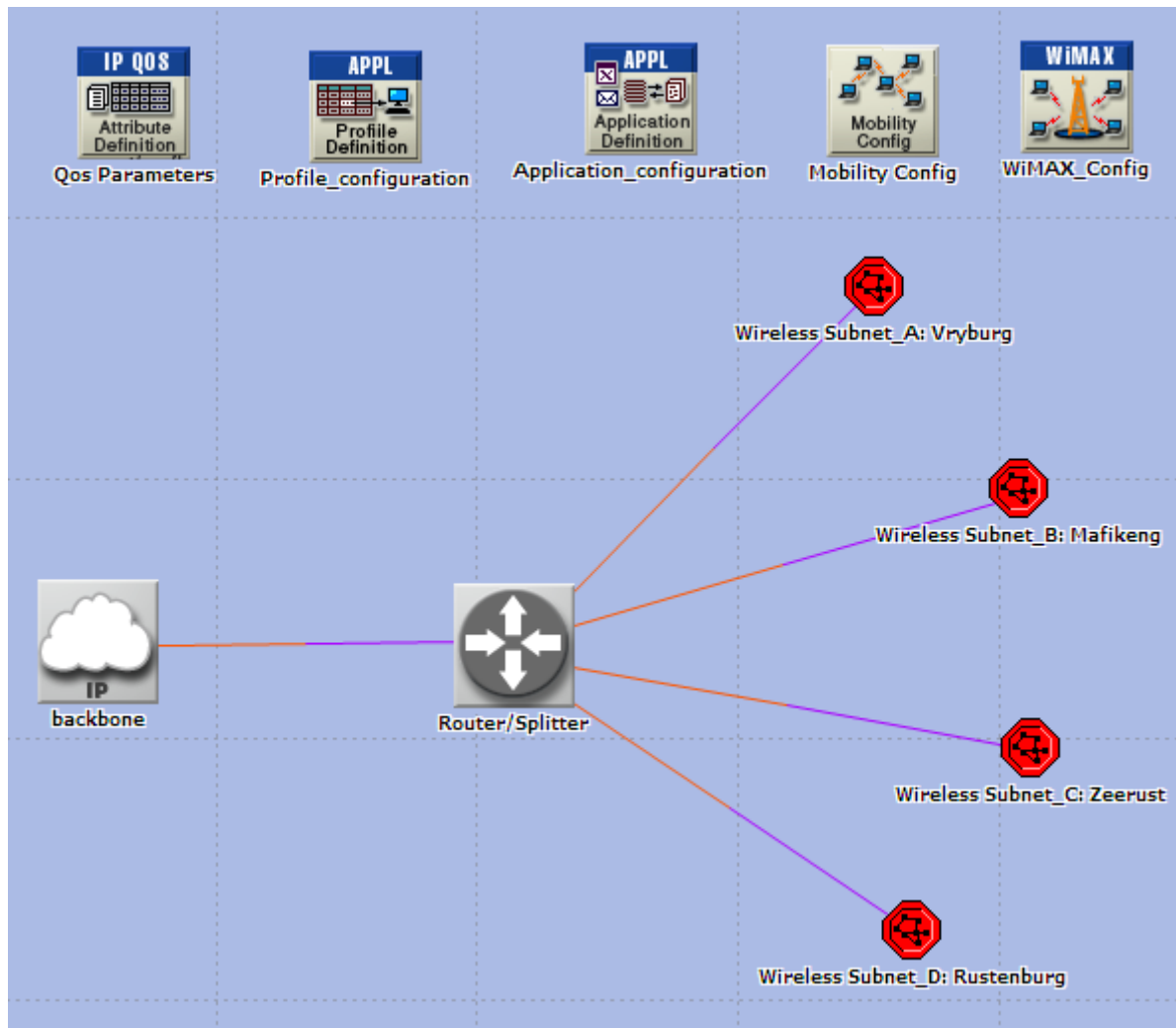

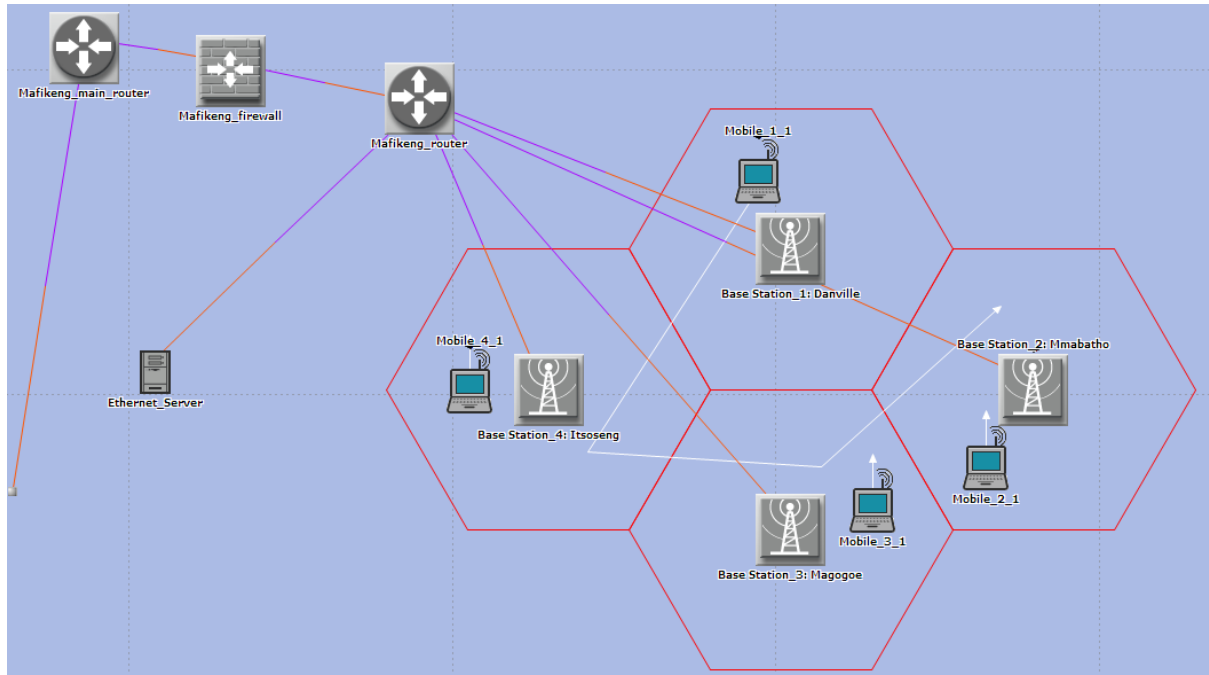**Figure 3. 13:** Metro network with QoS (North-West province).

Figure 3. 14: Network with QoS (wireless Subnet-B) Mafikeng.

Following are the actual utilities available in OPNET.

3.5 Configuration Utilities

The configuration utilities of the network model control and monitor the network and its traffic. These utilities show how each was configured during the network modeling. We use the following configuration utilities in this research:

3.5.1 Application Configuration

This object contains a list of predefined applications (http, ftp, voice and video conferencing) that can be utilized in the profile. Application configuration is responsible for generating any type of application traffic. In our work we chose to use http application to generate our network traffic. It is the source of traffic because it is where we configure applications to create profiles that use this application. As depicted in figure 3.15, we set the http attribute value to heavy browsing [62].
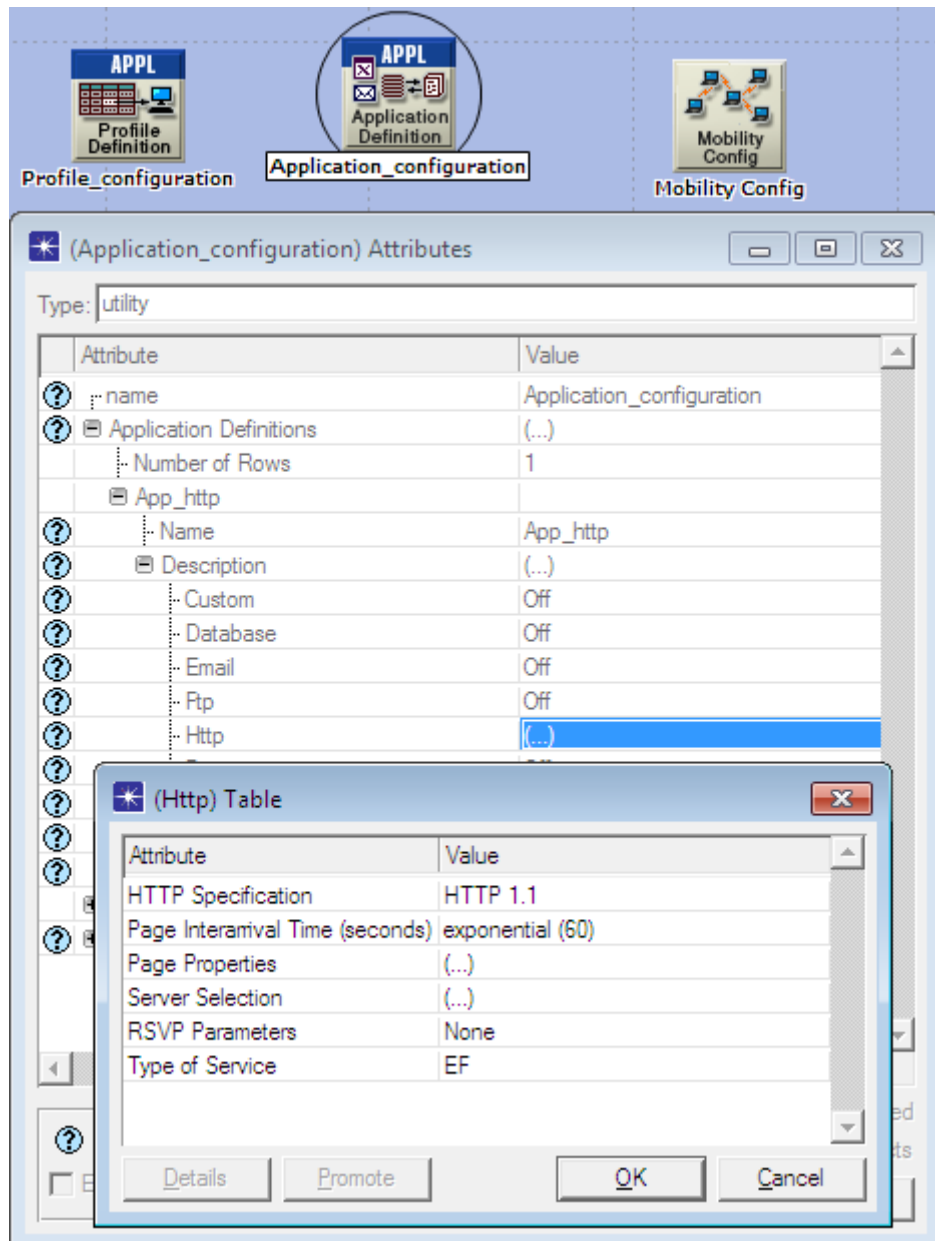
Figure 3. 15: Application Configuration.

3.5.2 Profile Configuration

Profile configuration allows us to create a profile that we can apply to nodes in the network. Figure 3.16 illustrates the http profile that was created to match our application traffic. We chose http statistics and results statistics to show the Page Response Time and Traffic Sent [62].
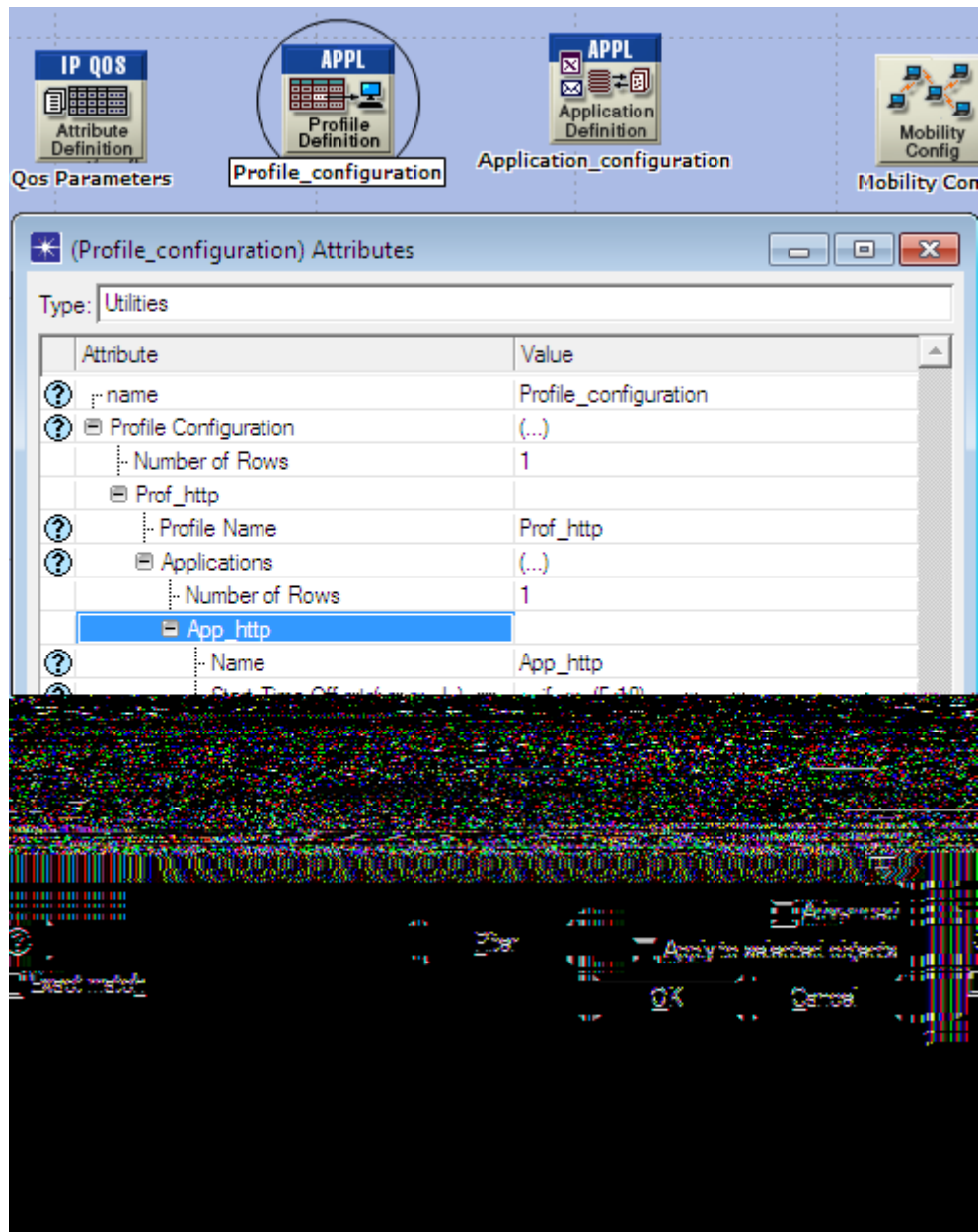
Figure 3. 16: Profile Configuration.

3.5.3 WiMAX Configuration

In this scenario is where the contention of MAC services and class definitions are chosen to enable mobility and ranging efficiency mode. Figure 3.17 shows WiMAX deployment in hexagonal network topology. OPNET provides an automatic network deployment tool called the wireless deployment wizard network creation. It allows deployments for wireless networks such as Wi-Fi, WLAN and WiMAX[62, 63]. We chose WiMAX to be our wireless front-haul network to maintain and provide QoS. In our work we increased the WiMAX frequency.
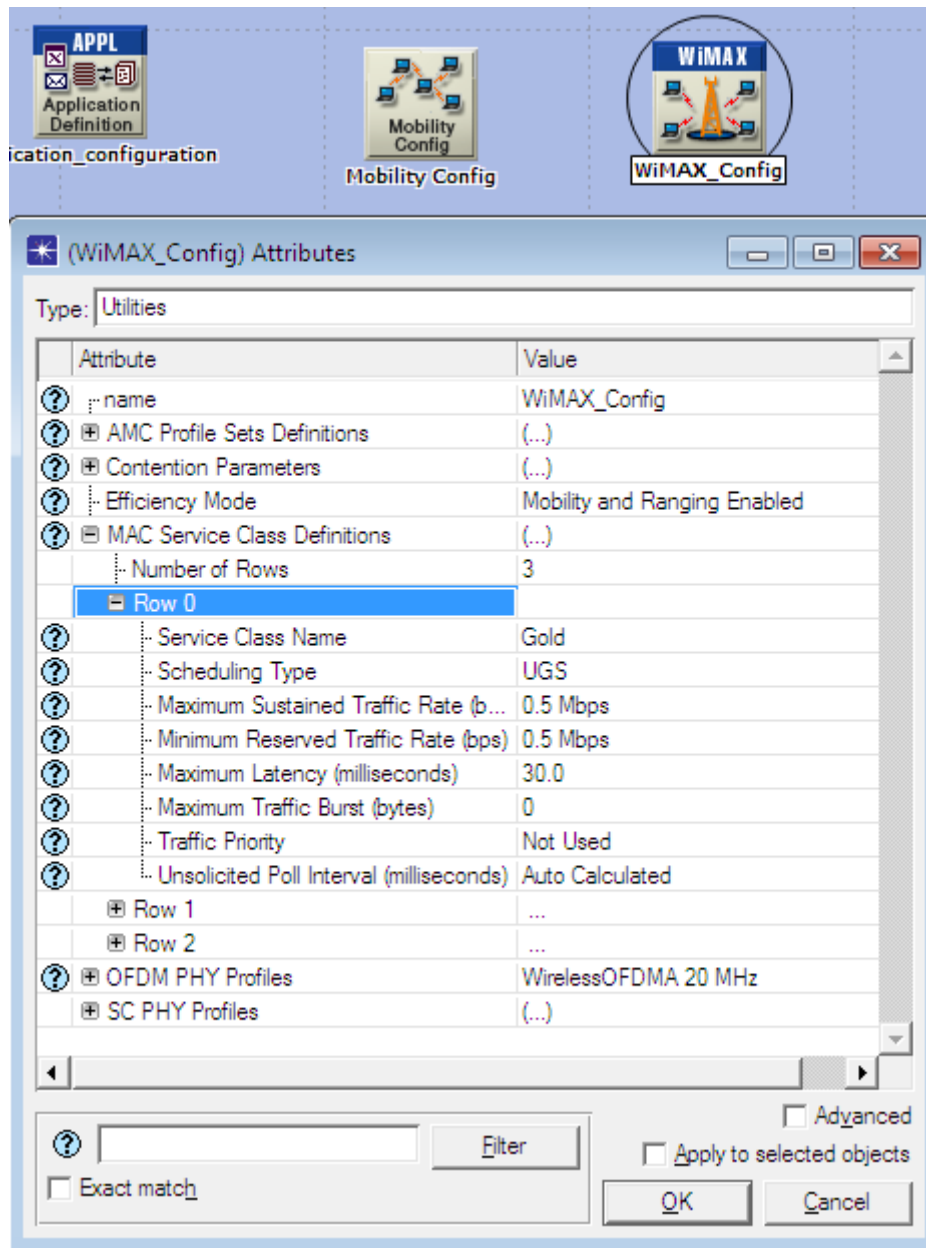
Figure 3. 17: WiMAX Configuration.

3.5.4 Mobility Configuration

This object shows movements via trajectories, focusing on the position and orientation of the mobile node. There are two types of trajectory being segment-based and vector-based trajectories, but segment-based trajectory was used for mobile nodes moving from one zone to another using Dynamic Host Configuration Protocol (DHCP). Figure 3.18 illustrates that each node can move within the coverage range of each Base Station (BS) within the four subnets. We chose segment trajectory to avoid BS bearing, so that our mobile nodes can automatically access any BS. Wireless mobile nodes may change their position and for this node movement is necessary [12, 62].
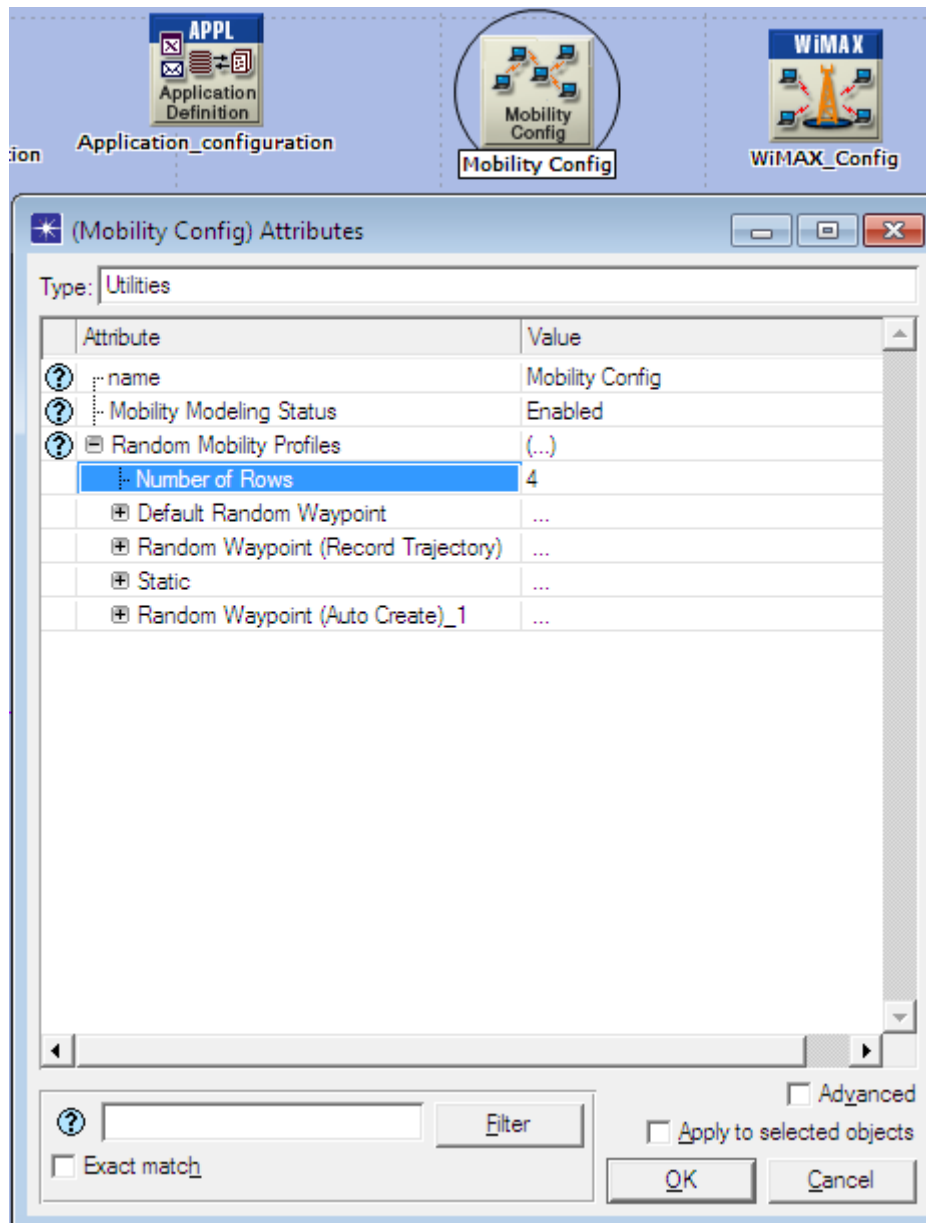
Figure 3. 18: Mobility Configuration.

3.5.5 QoS Parameter Configuration

Queuing discipline WFQ was configured in this object to invoke QoS parameters. As illustrated in figure 3.19, we did not use FIFO and PQ. However, in our work we chose to implement the WFQ mechanism to priorities application traffic. The merits of FIFO and PQ coexist in WFQ. WFQ was configured and assigned traffic to enable expedited forwarding (EF). EF provides resources to sensitive real-time and interactive traffic. We chose EF in the WFQ to reduce delay, jitter and packet loss. It assures high bandwidth to end-to-end services. We utilized Differentiated Service Code Protocol (DSCP) to support the http application for generating traffic in our simulated model. DiffServ classifies and manages network traffic. It

provides QoS and uses EF to reduce traffic congestion. Scalability and flexibility are the main building blocks of QoS. It assures better quality to the application traffic. QoS parameters ensure a congestion free network, whenever, there is traffic traversing the network. Where there is network congestion, QoS aims to generate a high amount of bandwidth to reduce the network bottleneck performance. QoS is measured and evaluated using the following five QoS parameters: delay, jitter, bandwidth, packet loss and throughput [12, 62, 63].

1. **Delay (Ethernet Delay)**

The finite amount of time it takes for a packet to be transmitted from the sender through the network to the receiver. It is also referred to as latency[63].

The following formulas are used for calculating delay in the network[67]:

Transmission delay: the time taken by the host to put data packets into the outgoing link.

$$transmission\ delay\ = \frac{packet\ length}{link\ bandwidth}$$

Propagation delay: time taken by the signal to reach one end of the link. It depends on distance and velocity. The two expressions of propagation delay are given as:

$$propagation\ delay = \frac{length\ of\ physical\ link}{propagation\ speed\ in\ medium}$$

$$propagation\ delay = \frac{distance}{velocity}$$

Processing delay: the time it takes for the packets to be taken by the receiver to be processed from the queue. We do not have a formula for processing delay.

Queuing delay: the amount of time packets queue in the buffer waiting to be executed. We do not have a formula for queuing delay.

End-to-end delay: calculates the overall delay over the network from source to destination.

$$delay_{end-to-end} = N(d_{tran} + d_{prop} + d_{proc} + d_{queu})$$

$$N = number\ of\ links\ or\ routers$$

$$d_{tran} = transmission\ delay$$

$$d_{prop} = propagation\ delay$$

$$d_{proc} = processing\ delay$$

$$d_{queu} = queuing\ delay$$

2. **Jitter (Traffic dropped)**

The difference in the end-to-end delay between packets over the same network. Jitter is also known as delay variation [62, 63]. Packets experience delay proportional to the packet size.

3. **Bandwidth (Page Response Time)**

The amount of data that can be transmitted in a fixed amount of time. However, it may not only be limited by the physical network infrastructure. Bandwidth is expressed or measured in bits per second (bps) or bytes per second [62].

4. **Packet loss (Traffic Received/Sent)**

It determines the maximum number of packets that are expected to be lost within a specified transfer time during packet transmissions within the network. Loss would be zero during non-congestion periods however, during congestion periods QoS mechanisms would determine which packets are suitable to be dropped to decrease congestion. TCP automatically resends lost packets which were not acknowledged but this process decreases the overall throughput [12, 63]. The expression of packet loss rate is given as:

$$loss\ rate = \frac{total\ number\ of\ dropped\ packets}{total\ number\ of\ input\ packets} * 2$$

5. **Throughput**

The amount of packets transmitted through a network at a specific time and is the amount of sent, received and processed packets in one determined time space. It is mostly useful in non-real time applications. Throughput is the successful delivery of packets over a network. It has end-to-end significance and measures the channel capacity of a communication link [12, 63]. The expression for calculating throughput is given as:

$$throughput = \frac{data\ trasmitted}{unit\ of\ time}$$
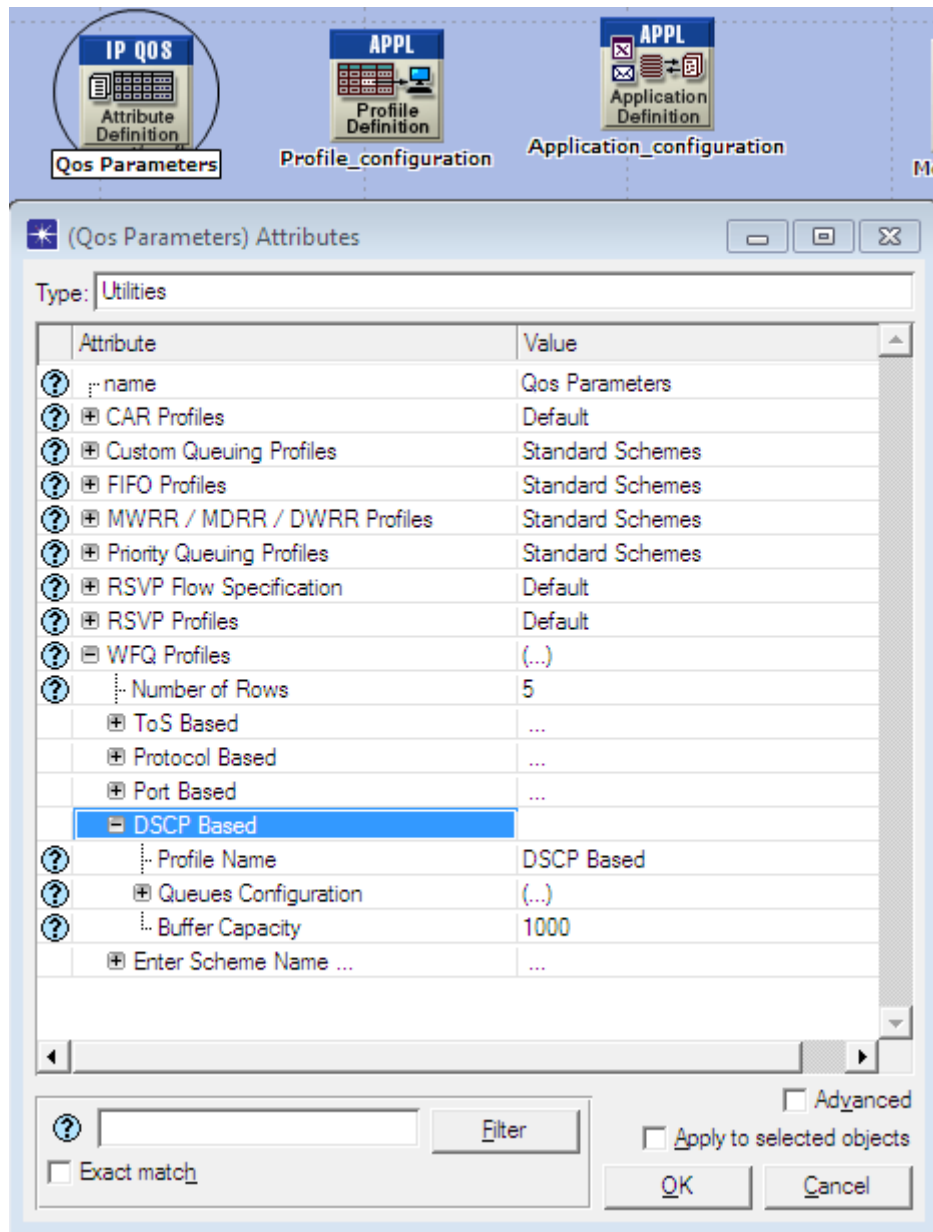
Figure 3. 19: QoS Parameters Configuration.

3.6 QoS Scenario

Http connects the user to the world and it can allow limitless browsing. It provides triple play services (video, voice and data) and it also enhances and reinforces business relationships, through the use of services such as video conferencing, internet banking and emails. Http reduces travelling expenses because everything the user needs is at the user's finger tips, mobile phones being a relevant example. Browsing the network is a daily routine to most users meaning that QoS is essential when coming to real-time on-demand applications and QoS has the ability to improve and guarantee transmission of higher bandwidth encrypted triple play services.

3.7 Network with QoS

QoS guarantees optimized broadband access by using scheduling algorithms to deliver diverse services to the user and it facilitates the routing protocols in the network traffic. The FiWi broadband access with QoS is a permanent solution to the access bottleneck in communication networks and it addresses high-speed broadband services for both rural and urban areas. QoS means services mobility and reliable broadband access. Uplink channel and downlink channel connections are mapped to a queuing discipline to enable DiffServ (Differentiated Service) to achieve better QoS scalability especially for real-time traffic and for security purposes. DiffServ used EF (Expedited Forwarding) to minimize the time packets spend in Weighted Fair Queuing (WFQ), because QoS provisioning is time, delay, jitter and loss sensitive. The most powerful backhaul, the optical broadband facilitates the QoS provisioning using the MAC layer and Optical Network Units (ONU) mechanisms.

3.8 Network without QoS

WiMAX dynamic characteristics introduce difficulties to support QoS due to severe packet loss, delay and interference. QoS provisioning is not strictly prioritized in this type of networks because the network traffic is facilitated by time consuming queuing disciplines which are often outdated such as FIFO queue, meaning the network is not reliable and time efficient. Scheduling services such as Best Effort (BE), are used in the networks without QoS because BE does not provide any sort of guarantee that transmitted packets are delivered.

3.9 Chapter Summary

In this chapter we presented the simulation setup; and design of our model which was simulated based on our research goal. The chapter had processes which included experimental design and simulation, it also highlighted the actual simulation tool we were utilizing and the conceptual model from the previous chapter was later designed into our model. We briefly explained QoS broadband access scenarios, and we obtained the results that we wanted and the results will be discussed in detail in the next chapter.

CHAPTER FOUR
RESULTS AND DISCUSION

4.1 Chapter Overview

In this chapter we discuss the simulation outcomes. The results obtained are based on both the network with and without QoS. Our network example was setup as described in chapter 3. The results obtained after simulation will be discussed in this chapter and in conclusion we will show or indicate the best and reliable QoS scenario according to the defined parameters.

4.2 Results

In this section, we presented a comparative analysis on network with and network without QoS using http server. Our research was based on simulating a network with QoS and without QoS in the FiWi broadband network. The results try to answer the research questions as posed in Chapter 1 and to decide which of the two networks is better and superior. The network was simulated and the results between the two scenarios are compared and contrasted in the Figures 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6.

The following Figures 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6 show results that are measured using time average of packets versus time. The simulation took 80 minutes (4,800 seconds) to be completed and the obtained results clearly illustrated the difference between the two QoS scenarios using different colours. The figures 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6 are in a form of line-graphs, whereby the x-axis represented time in seconds (s) and the y-axis denoted the delay in packets in seconds (s).

4.2.1. Ethernet Delay (sec)
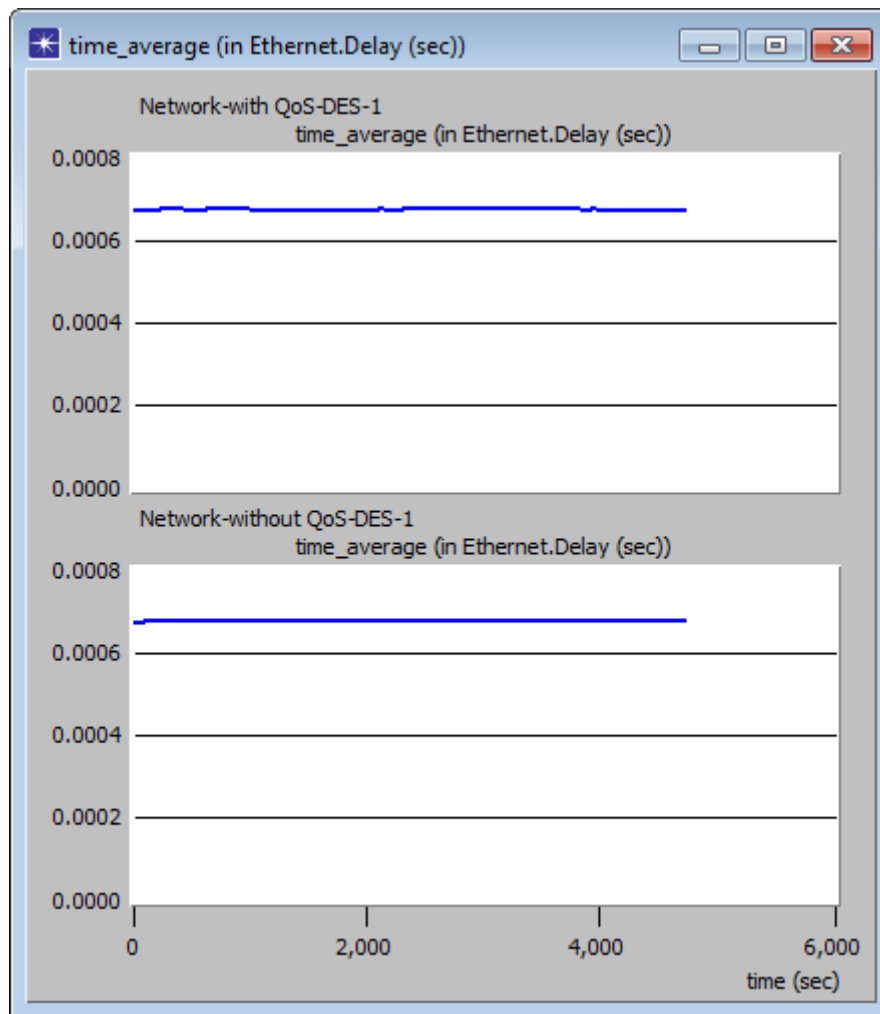
Figure 4. 1: Ethernet delay http heavy browsing.

In figure 4.1 we showed Ethernet delay within the radius of the base station in the wireless subnets, observing the network with and without QoS. In order for Ethernet protocols to work efficiently, the WLAN architecture is needed which WiMAX seamlessly supports in the IEEE 802.21 hangover.

Figure 4.1 showed constant delay according to the traffic congestion in the broadband access. The delay on both graphs was identical between 0.0006 and 0.0008 seconds. The latency outcomes were expected because of the timing variation of packets, so a delay inevitably occurred due to queuing and transmission time happening at the router.

4.2.2. Traffic Dropped
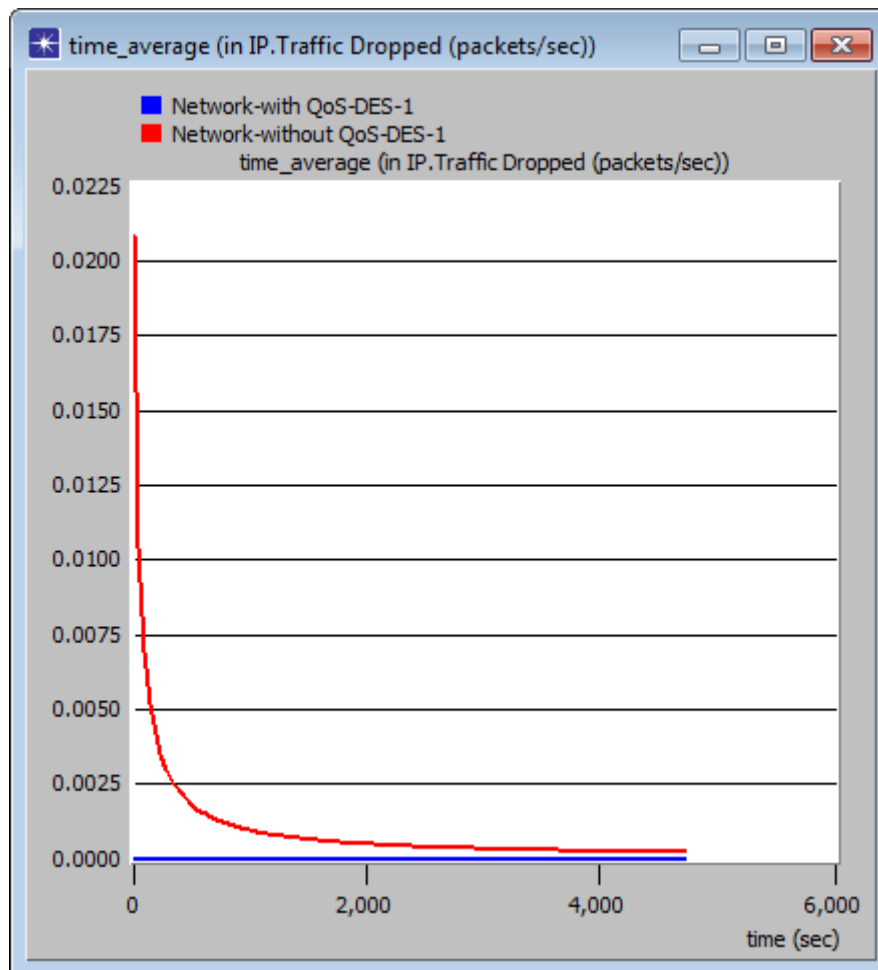
Figure 4. 2: Traffic dropped http heavy browsing.

The figure 4.2 illustrated typical network congestion where one or more packets in the FiWi broadband access failed to reach their destination, using queuing disciplines.

In this protocol there was no traffic dropped in QoS network but packet loss occurred in the other network without QoS. Network without QoS experienced exponential decay, while the other network experienced no packet loss because WFQ protects and priorities packets using congestion avoidance mechanisms. Non-QoS network dropped more than 0.0200 packets at the start time 0 seconds.

4.2.3. Page Response Time
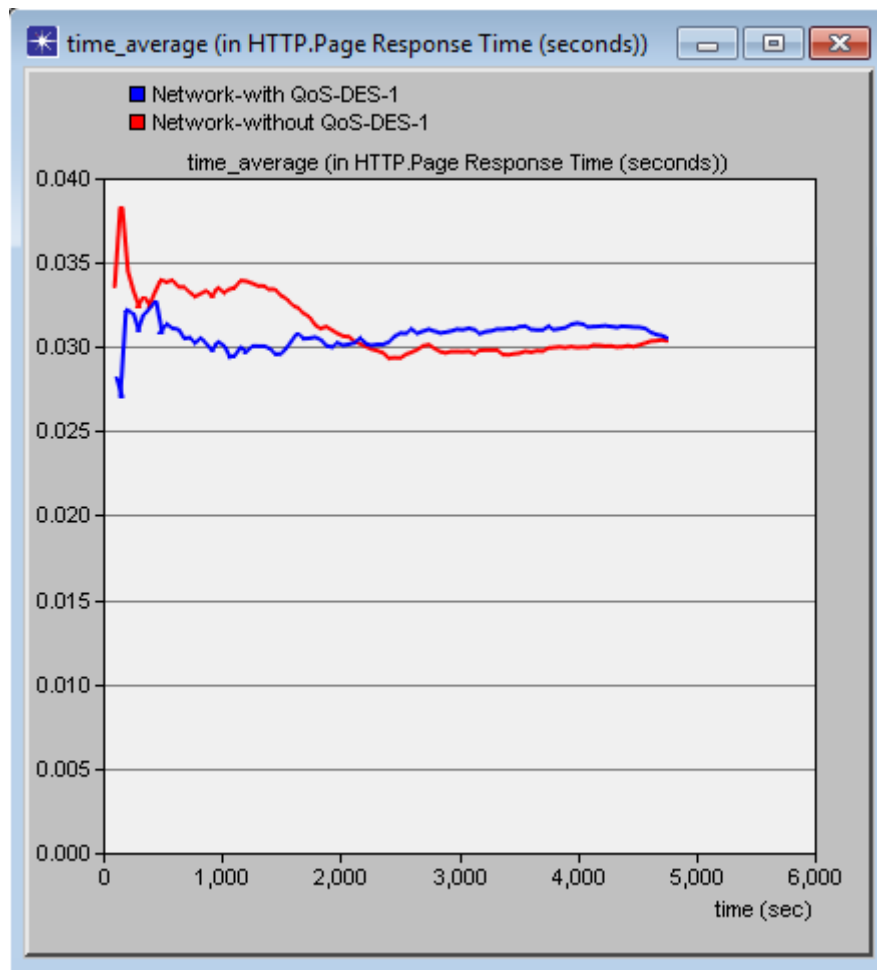
Figure 4. 3: Page response time http heavy browsing.

Figure 4.3 showed http server delay, the time the sever takes to load each web page using http heavy browsing and it was done for both scenarios.

The analysis of http heavy browsing showed that from time 0 seconds both networks were different. Network without QoS used the Best Effort (BE) service because in this service all packets are treated the same, meaning it takes less time to load a web page. It is difficult for WFQ to implement high speed network traffic because it will first weigh the packets before loading the web pages, meaning BE is not time consuming when compared to WFQ. At approximately 2,000 seconds the two networks had the same page response time. After 2,000 seconds the BE traffic continued to drop packets for loading web pages because it lacks QoS.

4.2.4. Traffic Received
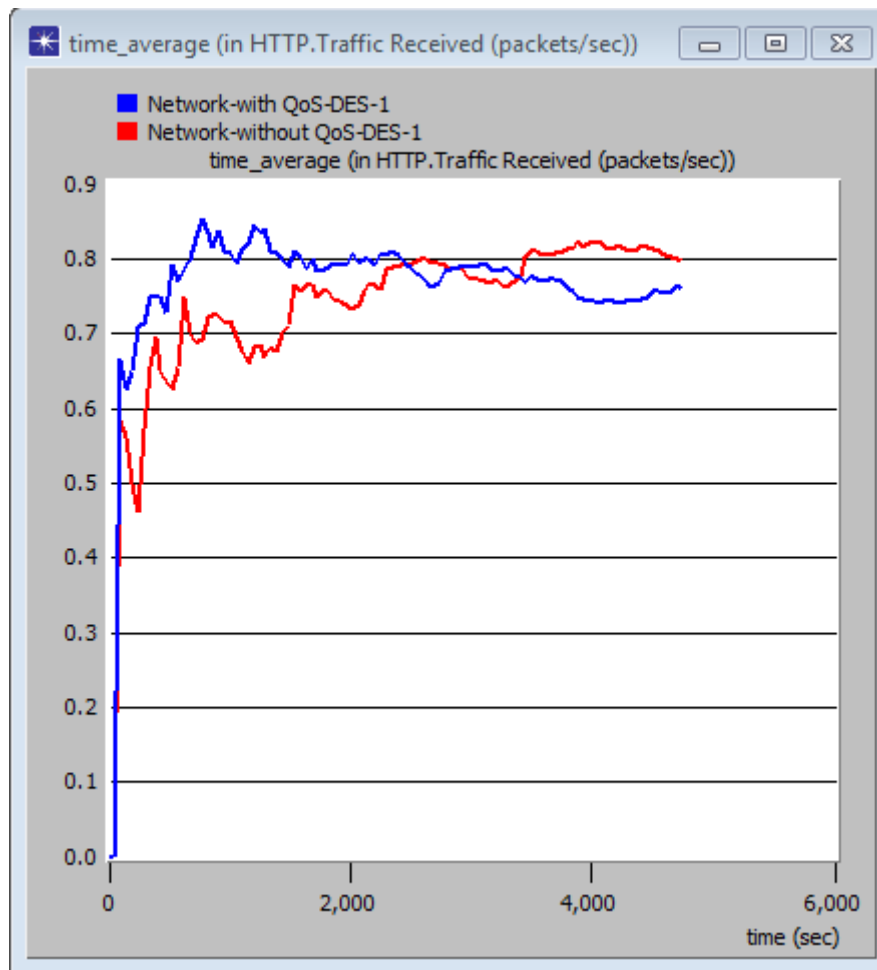
Figure 4. 4: Traffic received http heavy browsing.

Figure 4.4 indicated traffic received in bytes per second. Initial traffic received, in this case both BE and WFQ number of packets were received at the same time. Both QoS scenarios received 0.6 packets at time 0s, immediately after receiving 0.6 packets, there were fluctuating packet received graphs caused by scenarios during the interval of 1,000s to 6,000s between 0.4 and 0.9 packet received.

In the simplest terms, we can conclude that QoS enabled network produces higher traffic received. Therefore, network with QoS performs better than network without QoS mechanisms, as indicated by the number of packets received by the QoS network. The higher the traffic received, the better the performance of the broadband access. When network congestion occurs the network without QoS continues to drop packets, but BE services had a lesser end-to-end delay compared to WFQ since it did not have mechanism to retransmit.

4.2.5. Traffic Sent
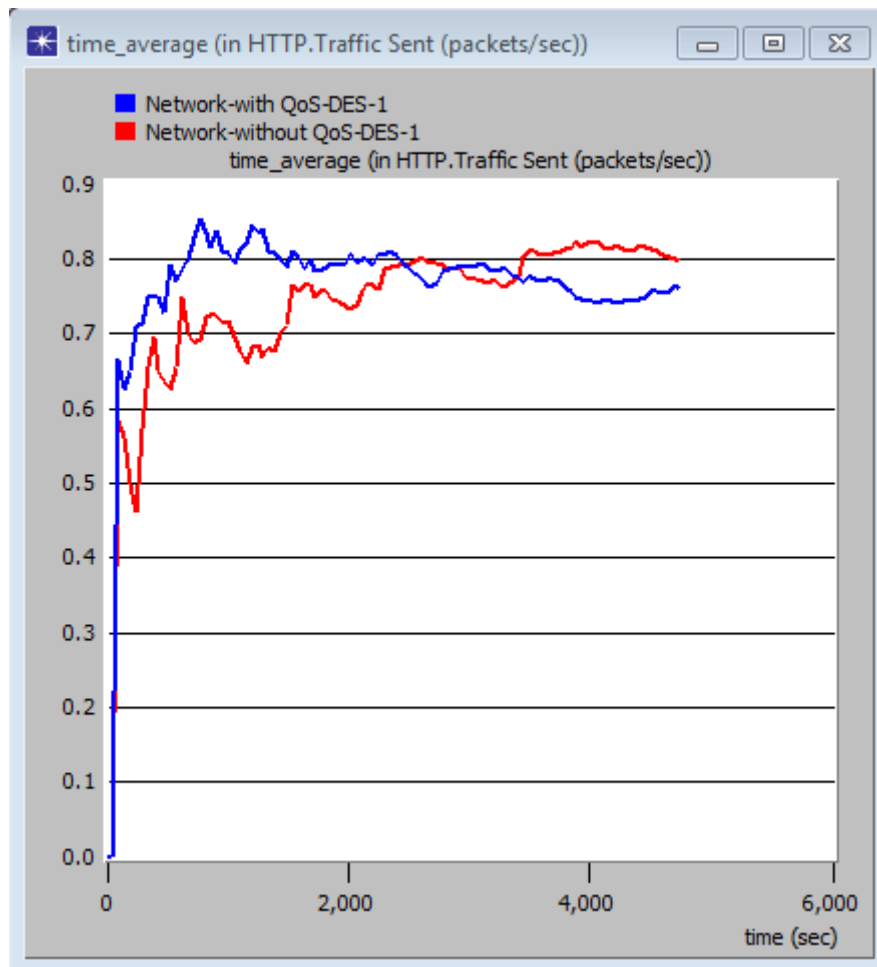
Figure4. 5: Traffic sent http heavy browsing.

Figure 4.5 illustrates the analysis of http heavy browsing traffic sent. Both traffic received and traffic sent are the same. Meaning that both outward and inward traffic have the same delay variation. The network with QoS had higher traffic sent because it prioritizes traffic using WFQ. BE services do not provide mechanism that retransmit corrupt or lost packets and has no guarantee of bandwidth for sending large packets. However, network with QoS performs better than network without QoS mechanisms, as indicated by the number of packets sent by the QoS network. WFQ reduces network congestion over the network.

4.2.6. Throughput
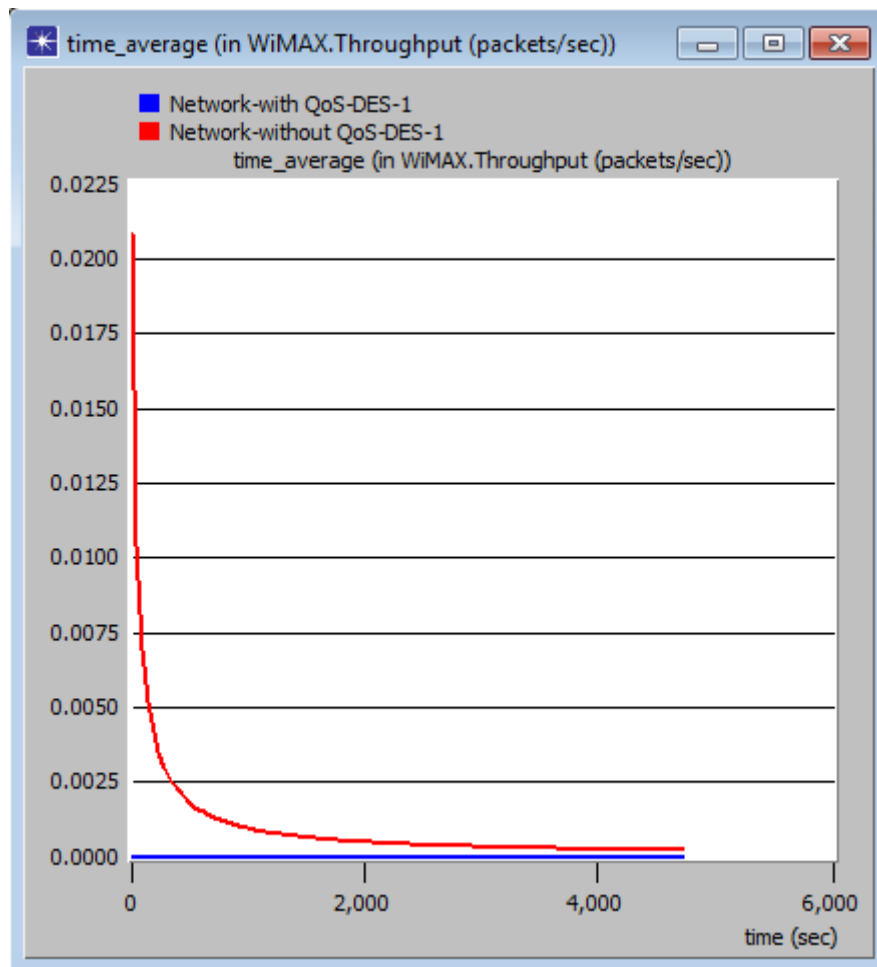
Figure4. 6: Throughput http heavy browsing.

Figure 4.6 shows the rate at which successful packets are being delivered over a communication channel. This protocol illustrates that traffic congestion in the QoS network was minimal during the transmission of packets through a medium. The was constant throughput in the QoS network, WFQ packets have priority to pass through Virtual Private Network (VPN) firewall in less time when compared to BE services because QoS mechanisms use Type of Service (ToS) to allocate headers to packets. QoS's main goal is to ensure sufficient bandwidth, reduce data loss, control latency and jitter. The network without QoS experiences latency and drops packets because it lacks ToS mechanisms such as DiffServ.

Throughput is analyzed by queuing disciplines, is mostly affected by various factors such as interference in WiMAX and distance limitations. QoS network uses an application level from throughput called goodput for guaranteed throughput, whilst BE services still suffer from

packet collision which has a huge impact on propagation delay. The network traffic congestion experienced in a network without QoS is due to the number of packets ending up being lost or the channel being overloaded and this is caused by BE delivery.

Efficient QoS becomes more relevant when the network is larger. The number of users utilizing broadband access in modern times is rapidly increasing.

4.2.7.   Results discussion

Telkom, MTN, Vodacom and Isizwe recognize the opportunities in offering broadband access with QoS to some sections in South Africa. Copper network architectures are postponing FiWi implementations. There is a performance bottleneck in the existing broadband networks, this central problem for both wireless and optical access is solved by the future network architecture that supports QoS called FiWi network. To improve and deploy future networks moving from copper network architectures is a challenge. Many organization utilize existing architectures such as copper and PONs, are unsure if they actually ready for FiWi implementations. Copper networks offer limited diverse services and FiWi helps in accessing broadband services including unlimited diverse services. PONs suffer from the physical impairments such as noise and attenuation. This dissertation educates the research community that FiWi is the future broadband network that provides QoS. The findings in this study indicate that FiWi network has security and is reliable.

Both network with QoS and without QoS are broadband accesses that are being widely used and deployed in many network architectures today. These two broadband networks have been discussed in the previous chapter and the results are shown in this chapter. They are both implemented in such a way that they accommodate triple play services using the http heavy browsing. Each and every day an online video from YouTube or Netflix is been streamed using http heavy browsing in a QoS network and on-demand applications such as live streaming (e.g. live radio, football and rugby), are also streamed using broadband with higher Bandwidth.

This work basically compares the two broadband access scenarios. As indicated and explained from above using the figures4.1, 4.2, 4.3, 4.4, 4.5 and 4.6we noticed and realized that between the two broadband networks which one is better than the other when comparing the two. This research clearly shows that the network with QoS is much better than the one without QoS in a hybrid broadband. This is due to WFQ which supports QoS because it uses traffic classification DiffServ to guarantee low packet loss, delay and jitter, it also uses QoS

parameters. If we take a closer analytical look back at chapter two where we briefly discussed the overview demand analysis of the hybrid architectures we realized and recalled that hybrid broadband architectures uses QoS support by converging two networking domains because the main goal of this research is to enhance efficient QoS support in our hybrid broadband access in a metro network. This hybrid architecture accommodates two types of internet traffic which are categorized as real-time and non-real-time traffic. BE delivery is similar in characteristics of FIFO queuing discipline because it is useful in many triple play services especially non-real-time applications but it drops and loses packets as indicated in figure 4.2, one can say that it is not reliable.

The results obtained in this chapter answer the research questions stated in chapter one, yes QoS network utilizes WFQ to minimize the queuing delay for time-sensitive triple play services that generate real-time traffic such as VoIP, video conferencing and on-demand applications; QoS mechanisms such as Random Early Detection (RED) schemes avoid real-time and non-real-time traffic collisions. EF used in WFQ is real-time sensitive for interactive traffic; QoS network provides fair resource allocation for both real-time and non-real-time applications, this method minimizes packet loss to make retransmission less frequent when streaming live triple play services and it improves throughput. BE service does not provide any guarantee of packets delivery and partially supports QoS, it does not provide any sort of special features that recover lost or corrupted packets.

4.3 Chapter Summary

This chapter answered our research questions from chapter one and it presented the results and performance evaluation based on QoS scenarios. The comparison between WFQ and BE; clarified which Queuing discipline was better than the other, between the network with and without QoS. From the results obtained above it was clear that in most cases WFQ showed to be the better services.

Chapter Five

Summary, Conclusion and Future Work

5.1 Summary

This chapter gives a summary of the work carried out in this research. It concludes by proposing directions for future work.

In chapter one, we introduced our framework. The QoS FiWi broadband access and related work were addressed in chapter two; including other authors work on this discipline that are directly related to this work. In chapter three we described the experimental setup that will be used to perform the simulation of the two scenarios namely: a network with QoS and one without QoS implemented by http heavy browsing. The methodology used is the experimental setup based on the framework for improved Quality of Service using the simulation tool OPNET. Chapter three was the experimental work whose results were presented in chapter four. In Chapter four, we explained the results obtained showing high bandwidth allocation, low latency and reduced delay being key factors for achieving QoS in the FiWi metro network architecture. Chapter five wraps up the whole research work and also indicates and highlights what will be done in the future concerning this research topic under future work.

Fibre-Wireless (FiWi) is a hybridized Dense Wavelength-Division Multiplexing-Passive Optical Network (DWDM-PON) with Worldwide Interoperability for Microwave Access (WiMAX) wireless network as means of providing higher bandwidth and efficient services. This research developed and implemented a framework for improved QoS for FiWi observing some specific QoS parameters namely: throughput, page response, traffic sent/received, traffic quality and traffic fluctuation.

5.2 Discussion Related to Research Questions

This section discusses and presents how the study's primary questions were answered.

1. How should the hybrid FiWi (FTTW) architecture offer triple play services (voice, data and video) in multimedia content forms?
2. How should one expect to avoid or reduce chances of distance limitations and can the architecture be resilient and overcome obstructions such as natural disasters, things beyond our control like poor weather conditions?

3. Is integrated QoS support compatible in this architecture and does it maintain levels of security, user mobility management and cost effectiveness?

5.3.1. Research Question One

Network without QoS uses BE service to transmit packets in the network using FIFO queuing discipline but FIFO drops and loses packets. FiWi supports QoS and uses traffic classification DiffServ. DiffServ is used by WFQ to guarantee low packet loss. FiWi broadband architecture offers multi-gigabit capacity reaching speeds of up to 26 000Gpbs to offer triple play services. WiMAX solutions offer 100Mbps of bandwidth. BE service is unreliable due to loss of packets when compare to QoS. FiWi architecture offers more bandwidth to streaming on-demand applications.

5.3.2. Research Question Two

FiWi network hybridizes Fibre and WiMAX to cover larger geographical areas and is a metro network architecture. WiMAX radius coverage is 50-70 km and WiMAX solutions are suitable solutions to wirelessly cover areas where wired networks cannot reach. Where underground fibre cannot reach, especially rural areas in those areas WiMAX will enhance QoS. Poor weather conditions cannot decrease the performance of optical fibre because fibre cables do not corrode or rust by using laser and photodiodes. Fibre networks are water resistant and resilient to network interference. PONs use less energy consumption per subscriber 0.2-0.8 Watts and PONs last for at least 60 years especially NBN. QoS in the FiWi minimises latency and avoids the use of optical buffers.

5.3.3. Research Question Three

Converging the two network domains: fibre and WiMAX to form an access network is cost-effective. The FiWi backbone is water resistant and can be deployed underground to run through the drainage system because the drainage system is cost-effective. IEEE 802.21 handover coexist wireless technologies to work together in a metro network architecture. NLOS WiMAX provide mobile coverage.

5.3 Research Contributions

The main goal of this dissertation was to evaluate QoS in FiWi broadband access in a metro network. Objective were achieved. FiWi architecture was deployed for a metro network in the North West province. The hybridized network domains formed a future network that supports QoS. QoS was evaluated using Queuing disciplines and WFQ was mostly used to support QoS. WFQ gives more bandwidth to packets with higher weight and WFQ

encompass the results of other queuing disciplines such as FIFO and PQ. QoS was evaluated using the five QoS parameters namely; delay, jitter, bandwidth, packet loss and throughput. The results were analysed using simulation tool called OPNET.

5.4 Conclusion

We analyzed the performance of QoS in the hybrid broadband access architecture observing the triple play services through packet loss rate, end-to-end delay, throughput and packet received and sent. For poor performance resulting in end-to-end delay during transmission, BE service has less end-to-end delay when compared to WFQ due to the fact that WFQ needs to firstly assign packets with relevant weights before transmission. WQF is the best service supporting QoS.

WFQ finds it difficult to implement the full potential of broadband because broadband access offers high speed network traffic for many concurrent processes and WFQ suffers from such high volume types of network traffic due to the fact that it needs to assign weights to packets before transmission and it is time consuming.

5.5 Future Work

End-to-end delay cannot be avoided. In order to minimize it there must be a model and mechanisms. Such a model makes sure that WFQ reduces queuing delay.

For future work we will need to focus on Machine to Machine (M2M) broadband architectures and how we can improve underground internet in the mines, underground transport internet and ocean cruise ship broadband. The next research should focus on converging M2M broadband with WiMAX and how they should utilize less energy consumption. Future WiMAX architectures should use DSTV antennas as broadband access points to supply broadband internet to many houses.

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