Resolving last-mile connectivity issues in Botswana using Wi-MAX IEEE802

Malebogo Mokeresete[1] iD <u>https://orcid.org/0000-0001-9676-2840</u> **and Bukohwo Michael Esiefarienrhe[2]** iD <u>https://orcid.org/0000-0002-1631-9759</u>

[1]   The Department of Computer Science and Information Technology, Sol Plaatje University, South Africa; m.mokeresete@spu.ac.za

[2]   Computer Science Department, North-West University, South Africa, Bukohwo Michael Esiefarienrhe; 25840525@nwu.ac.za@gmail.com

Abstract: Amongst advantages of using Worldwide Interoperability Microwave Access (WiMAX) technology at the last-mile level as access technology include an extensive range of 50 km Line of Sight (LOS), 5 to 15 km Non-Line of Sight and few infrastructure installations compared to other wireless broadband access technologies. Despite positive investments in ICT fibre infrastructure by developing countries, including Botswana, servicing end-users is subjected to high prices and marginalised. The alternative, the Wi-Fi hotspot initiative by the Botswana government, falls far as a solution for last-mile connectivity and access. This study used OPNET simulation modeller 14,5 to investigate whether Botswana's national broadband project could adopt WiMAX IEEE 802.16e as an access technology. Several developing countries in Africa and the world use WiMAX technology at access level and gain impressive results. The rampant lack of infrastructure development and the need to provide high-speed technology has necessitated such investigation. Therefore, using the simulation method, this paper evaluates the WiMAX IEEE 802.16e/m over three subscriber locations in Botswana. The results obtained indicate that the deployment of the WiMAX IEEE 802.16e standard can solve most of the deployment issues and access at the last-mile level. Although the findings suggest that WiMAX IEEE 802.16e is more suitable for high-density areas, it could also solve rural areas' infrastructure development challenges and provide required high-speed connectivity access. However, unlike the Wi-Fi initiative, which requires more infrastructure deployment and less on institutional and regulatory frameworks, the deployment of WiMAX IEEE802.16e requires institutional and regulatory standards.

Keywords: WiMAX IEEE 802.16e; National Broadband Project; rural area connectivity; Connectivity challenges in developing countries

1.   Introduction

Generally, the public has expressed concerns that the national broadband project intended to provide affordable and universal services has not delivered results and failed. This situation has led the public, including former senior government official the Minister of Works, Transport & Communications, David Magang, to express dissatisfaction about the project failed to meet targets and deliverables of the national broadband project rollout [1]. Magang has warned that connectivity and access could generate a distant dream than realistic aspirations due to lack of affordability, quality service and access. The former Minister decries the persistent lack of affordable internet access and practical high-speed Internet and further warned the government to review the national broadband project and ensure intended goals for innovation and creativity as the bedrock of the economy realised [1]. Many villages in Botswana with proximity to cities, towns, and urban areas, one connected and the other not. For example, Kopong, Matseta, Gakuto, Ga-Modubu and Manoko cluster villages experience broadband access disparities, yet close by not more than 10 kilometres from each other. Also, many villages clustered together exist and experience variant high-speed networks, for example, Samochima, Shakawe, Sepopa and

other cluster villages. The pattern suggests that service providers experience colossal costs to provide service due to sparse settlement patterns. However, the national broadband project faces infrastructure deployment and relevant technologies challenges, which affect connectivity at the last-mile level [2]. WiMAX IEEE802.16e, a relatively new access technology that allows interface with LTE technologies, presents an opportunity (El-Moghazi, Whalley, & Irvine, 2014) for Botswana's aspiration for a knowledge-based economy. Developing countries, including Botswana, experience high infrastructure network development costs, exacerbated by highly scattered settlement patterns, low population density, and low incomes challenges [3]. These challenges affect the determination of broadband services and marginalise areas with lower economic potential for urban areas where more people have income and are highly likely to use broadband services.

Despite substantive and successful national fibre infrastructure investments, institutional and regulatory frameworks, many people cannot afford broadband services in Botswana. For example, in a study of 230 countries, Botswana ranks 167 amongst the most expensive internet access and experiences urban skewed broadband services at the last mile [4]. However, despite developing countries infrastructure challenges, the preferred deployment technologies should address the problems of low populations densities, low rural incomes, and sparse settlement patterns, which affect the successful deployment of broadband services. Although many countries introduced Wi-Fi services to reduce access costs to subsidise users and improve efficiency, such initiatives present regulatory challenges. Government agencies that provide wholesale and spectrum management services by providing Wi-Fi hot spots services has turned into providers and competitors to ISPs and MNOs. Also, instead of focusing on management and control of the fibre backbone, the government has delved into providing hotspots to users, which invariably creates disparities and ineffective in-service delivery. Such conflicting roles assumed by the government suggest a gap that requires developing another institutional framework, which would provide primary and subsidised services as roles to be managed by the government.

The literature review on broadband development in developing countries rests with wireless technologies than wired, and WiMAXIEEE802.16e stands out as the likely candidate for connectivity and access at the last-mile level [5]. The discussion that follows presents WiMAX IEEE802.16e testbed simulations, determining whether the government could benefit from the technology as an access medium for the last mile. However, given the glaring connectivity and access challenges of the national broadband project, BOCRA's 2019-2024 Strategic Plan remains unrealistic.

2.   Background

Studies indicate that Developing countries settlement patterns present infrastructure development challenges [6]. The settlements have both close and scattered proximity, lower population densities and incomes, which affect resource mobilisation and fair distribution of infrastructure development and business viability. Furthermore, low population densities, lower rural incomes, and lack of local application content affect broadband services, including internet use. However, the challenges include the lack of institutional capacity, the void created by high prices charged by MNOs and the lack of Primary network access to provide an alternative. Governments across developed and developing introduced Wireless Fidelity   (Wi-Fi hot spot) networks, affordable rates, internet access and improved efficiency. Despite Internet price reduction by the wholesaler, ISPs in Botswana decry the high termination costs, explaining high retail prices charged service end-users, and has led many people to question the regulator's role.

Communities in developing countries often settle in sparse-location patterns approximately 10 to 40 kilometres apart and demand MNOs and ISPs to install more ICT infrastructure and strain budget resources, yet strain MNOs resources [7]. For example, Good Hope, Tlhareseleele, Rakhuna [8] and other closely related villages could benefit from access technologies that require less infrastructure, such as WiMAX IEEE 802.16e.

Many governments across developed and developing countries introduced the Wireless Fidelity (Wi-Fi) networks to subsidise service end-users, improve efficiency and political expediency. For example, many people applauds BOFINET Wi-Fi hot spot initiative, particularly in the banking sector, public Wi-Fi services have eased congestion and enhanced service delivery. As a result, many people access statements, transfer funds and other online services outside banking halls. Also, the Wi-Fi hotspot initiatives presented service end-users with alternative access from the high tariffs charged by MNOs and ISPs to access broadband services. However, despite the Wi-Fi hotspot's positive advantages, the infrastructure has limited capacity, requires extensive network infrastructure deployment, and may not work for rural areas. It requires a series of network installations, including institutional and regulatory frameworks, to address the entire country's broadband needs.

Nevertheless, developing countries could adopt wireless technologies to address the prevalent lack of infrastructure, high and lower infrastructure deployment costs. The Worldwide Interoperability for Microwave Access (WiMAX IEEE802.11), cellular mobile wireless technologies and hybrid fibre-wireless holds answers for successful deployment of broadband service access. Furthermore, WiMAX IEEE 802.16e has demonstrated beyond other wireless technologies capacity to provide connectivity and access for developing countries due partly to low population densities, lower rural incomes and infrastructure-less environment. Therefore, it has become imperative to conduct a simulation testbed to determine the appropriateness of WiMAX IEEE 802.16e as access to internet services for the entire country at the last-mile level.

3.   Literature Review

Lack of adoption of the relevant access technology, infrastructure development, low populations, and inadequate local application content in developing countries subdued internet penetration [9]. As a result, governments face the daunting task of providing connectivity and ensuring that end-users can access e-gov and other essential online services. Failure to ensure that citizens, regardless of location, access the Internet could create two types of citizens, one without access and not benefiting, while some benefit resulting in class differences and subsequent dissatisfaction among the general population, which could invariably lead to internal crises. In hindsight, the government should meet various obligations; national development programmes, Millennium Development Goals (MDGs) and International Telecommunication Union treaties (ITU). However, connectivity and access challenges present opportunities for the government and other broadband stakeholders to shop for technologies to address the challenges. Another challenge facing developing countries, including Botswana, is the rampant lack of support infrastructure development, such as lack of household power (electricity) connectivity, inadequate road networks, and equipment security.

Despite limited WiMAX installations and LTE dominance in Botswana, MNOs, ISPs, and BOFiNET have deployed the technology on some sites. According to the Research ICT Africa report, Angola, Mozambique, Nigeria, Namibia, Ghana, and other countries adopted WiMAX as an access technology in the region and has improved internet penetration, affordability and mitigated connectivity challenges [10]. Although the WiMAX standard body withdrew the WiMAX 802.16a/b/c, currently 802.16d/e/m are available and provides around 50km for the Line of Sight or fixed stations and 5-15km for non-Line of Sight or mobile stations [5]. The WiMAX IEEE802.16d could provide 70Mbps, 802.16e-15 Mbps and 802.16m-100Mbps when installed. Also, the   WiMAX standard provides three alternate topologies: fixed point to point (P2P), fixed point to multipoint (P2MP) and mobile WiMAX [5]. A mobile WiMAX topology relies on the collaborations of base stations to relay communication to subscriber stations and mobile devices that support a series of overlapping cells, which relay a signal to another base station cell and provide access [5].

Liang emphasis that only the deployment of wireless access technologies could address the rural broadband connectivity challenge through deploying wireless access technologies, especially WiMAX technology [11]. Liang et al. point out that wired technologies

require infrastructure installations often incompatible with developing countries' settlement patterns, which leads to higher deployment costs than wireless technologies. The reliance on wired technologies has led developing countries to fail to deliver on several connectivity commitments, government, Commonwealth Telecommunication Organization (CTO) 2015 and International Telecommunication Union (ITU) 2016. Despite positive institutional and regulatory milestones, the RIA Botswana ICT report [12] found that Botswana's ICT readiness ranking has deteriorated to the worst levels. The ICT report attributes the national broadband project's deterioration to the universal service obligations (USO), weak tariff regulation, poor quality of service (QoS), and other value-added network services, dimensions to high termination costs and skewed market [12]. Also, the ICT report found that only 9% of their study respondents use the Internet and resides in urban areas, while the rest of the country experience lack of internet connectivity access [12].

Orange Botswana report that the deployment of WiMAX IEEE802.16e significantly improved QoS and affordability of the internet connections in Francistown and Gaborone [13]. Although the WiMAX standard body initially developed technology for metro and high-density areas access, it has successfully demonstrated connectivity and access for rural areas with less infrastructure deployment.

4. Methodology

Various researchers have made a tremendous contribution to simulation and modelling techniques. Shannon defined simulation as the design of a conceptual model to conduct experiments to understand a system's performance and evaluate alternative methods.   Simulation is seen by Sekaran & Bougie 2016 [14] as an opportunity to understand and solve computer-based problems. While [15] define simulation as the process of using inputs to drive a model while observing its output as the model is working [15]. While Shannon simulation steps consist of 11 steps: System Definition, Model Formulation, Data Preparation, Model Translation, Validation, Strategic Planning, Tactical Planning, Experimentation, Interpretation, Implementation and Documentation, these steps are helpful for both engineering and computer science projects [16]. A similar simulation procedure consisting of thirteen (13) steps is given by Seila in [17] as follows: Problem Statement and Objectives, Systems Analysis, Analysis of Input Distribution, Model Building, Design and Coding of Program, Verification of the coded program, Data Analysis and Design, Model Validation, Experimental Design, Making Production Runs, Statistical Analysis of Data, Implementation and then Final Documentation. These steps are more aligned to computer science research that involves both software development and data collection.

This research adopts the simulation as defined by [14]. Despite many variances in networking tools from easy to use to complex ones, they remain an essential tool for researchers, for example, (1) QualNet, (2) NetSim, (3) SSFNet, (4) NS2 and other simulation tools. They also vary from open, commercial, proprietary, and accessible for academic and non-profit [18]. Table 1 present a few of the list of simulation tools and their comparison using vital characteristics.

Table 1. Comparisons of some network simulation tools [14]

Name	License Type	Language	Supported Operating	GUI Support	Document Available	Ease of Use

QualNet	Commercial (Separate license for academicians and others)	C++	UNIX, Window-MAC, Linux	Yes	Excellent	Moderate
NetSim	Proprietary	C and Java	Windows (7, Vista) and Windows XP	Yes	Excellent	Easy
SSFNet	Open-source	Java and C++	Linux, Solaris, and Windows NT using JDK1.2 and higher	Yes	Good	Hard
OPNET	Commercial	C and C++	Windows XP, Vista, 7 & Windows NT 4.0	Yes	Good	Easy
Ns2	Open-source	C++and OTCL	GNU/Linux, Free BSD, Mac OS X, Window XP, Windows Vista and Win. 7.	Limited	Excellent	Hard

5.   Setup Model Network and Implementation

The study used OPNET Optimised Network Engineering Tools (OPNET) simulation tool, 14.5 modellers. OPNET is user friendly, primarily through the Graphic User Interface (GUI) embedded in the tool and operation protocols used to simulate wired and wireless communication systems [14], [19]. Also, the simulation tool is popular amongst ICT, research, and military circles and involves the following process steps, in Figure 1.

- Creation of the network Model
- Choosing statistics to be collected
- Running the simulation
- And finally, view and analysis of the result.
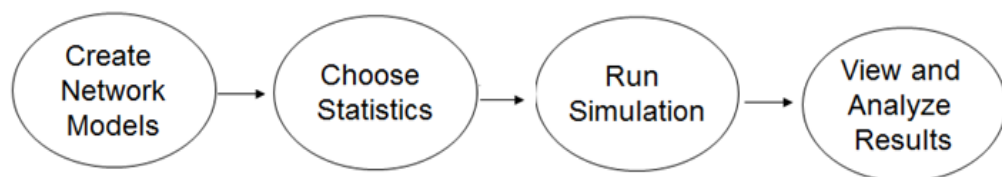
Figure 1. Implementation of OPNET 14.5 modeller simulation

5.1 Structure of OPNET 14.5

5.1.1   Network Domain

The network domain reflects the scope of the network simulated. It depicts networks, sub-networks, network topologies, objects in the network and various configured simulation parts.
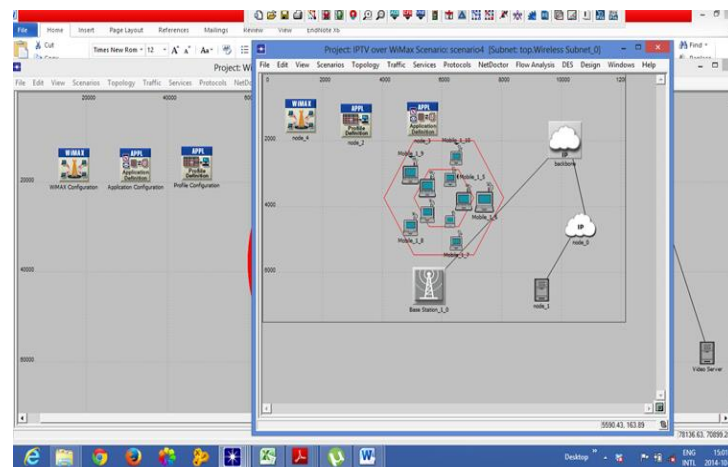
Figure 2. Network Domain

5.1.2   Node Domain

The node domain goes inside the actual structure of the network node. Nodes could be the satellite terminals, base stations, subscriber stations, switches, servers, routers, and other sub-systems, fixed or mobile. The subscriber station node model is used to build all the nodes used in the node editor.
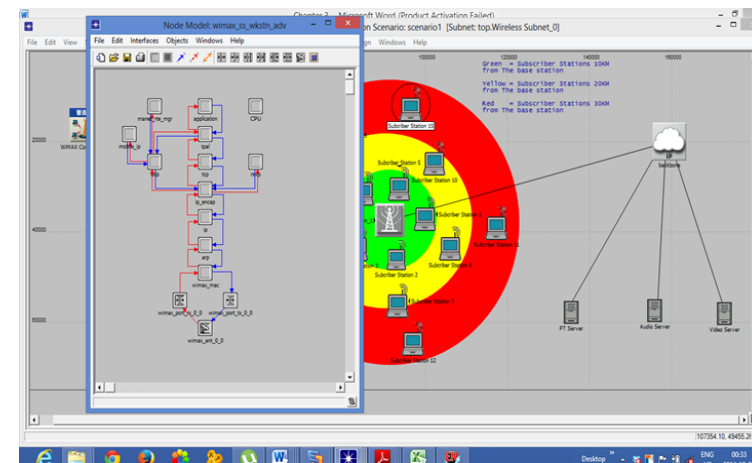
Figure 3. Node Domain

5.1.3   Process Domain

The process express domain in C and C++ source codes also specifies how the processor model behaves. Generally, the process models control the node model's primary functions generated in the node editor.
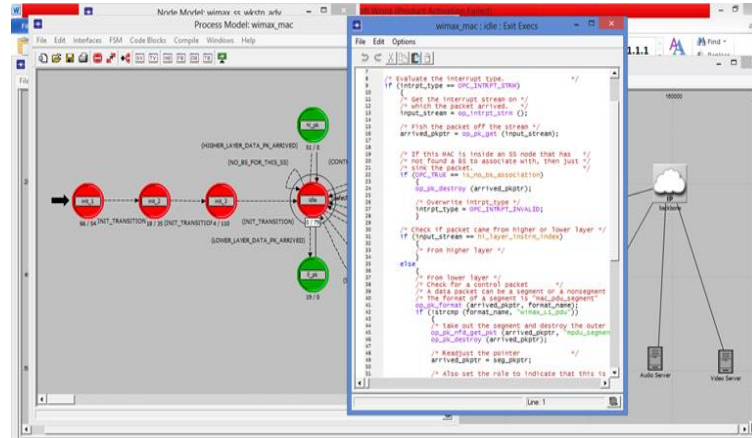
Figure 4. Process Domain

5.2 WiMAXIEEE802.16e performance metrics used

5.2.1 Traffic Sent and Receive

Traffic sent is the amount of data transmitted by the WiMAX MAC in packets/sec or bits/sec. WiMAX MAC sends average bits/sec to the transport layer for network transmission, file transfer protocol (FTP), and video-conferencing for voice applications. Traffic Received is the amount of data traffic transmitted successfully and received by the WiMAX MAC from the physical layer, either in packets/sec or bits/sec. For example, Traffic Received would be the average Packet/data rates forwarded to the video conferencing application by the transport layer in video conferencing. The calculation to evaluate the Traffic sent/received, and the study considered the WiMAX MAC packet delivery ratio (PDR), which here presents the formula for packet delivery;

$$\text{PDR} = \frac{\Sigma(\textbf{Total packets received })}{\Sigma(\textbf{ Total packets send})} \qquad\qquad [20] \qquad (1)$$

5.2.2 Delay

Transmission delay is the end-to-end delay of packets received and is one of the many networks' most essential performance measurements. Delay usually specifies how long it takes for a packet/data to travel from the transmission link to the receiver node. The moment the packet leaves the transmission site or sources, it goes from the switches and is then directed to other links in the network until it reaches its destination. In simpler terms, transmission delay is the time needed to transmit all bits via a transmission medium.

$$t = N/R \qquad\qquad\qquad [20] \qquad (2)$$

Where;

N= Number of bits in a packet

R= total Number of transmitted packets

5.2.3 Jitter

Jitter is the variance in delay as the transmission send packets through the network. As the transmission sends packets, they are continuous and fragmented as they arrive at the receiver, mainly because of congestion. Jitter mostly happens when the network experiences congestion, interference, some router path changes etc.

$$\text{Jitter J} = \mathbf{D}_{i+1} - \mathbf{D}_i \qquad\qquad [20] \qquad (3)$$

Where;

D= forwarding delay

i = packets received

5.2.4 Traffic Dropped

Traffic Dropped (packet lost) is the Number of packets that failed to reach their destination, resulting from network interference and network congestion. To measure the traffic/packet dropped relies on packet loss rate formula;

$$PLR = \frac{N^{tx} - N^{rx}}{N^{tx}} \times 100 \qquad\qquad [21] \qquad (4)$$

Where;

PLR = Packet Loss rate

N^{tx} = total Number of transmitted packets

N^{rx} = total Number of received packets

5.3 Simulation parameters

The Simulation bed use a WiMAX base station linked/connected with nodes that form part of the network in real situations, shown in figure 2 (Network model figure). The nodes include; WiMAX base station, application servers, internet connection (represented by cloud), routers, computers or CPE(Customer Premises Equipment)

The applications rely on Application Configuration. Table 2 below summarises various simulation scenarios; profile configuration creates user profiles specified on different nodes to generate application traffic in the network and use Application Configuration to configure profiles. The same configurations a applied in 3 scenarios; the only difference was the distance of each scenario from the WiMAX base station.
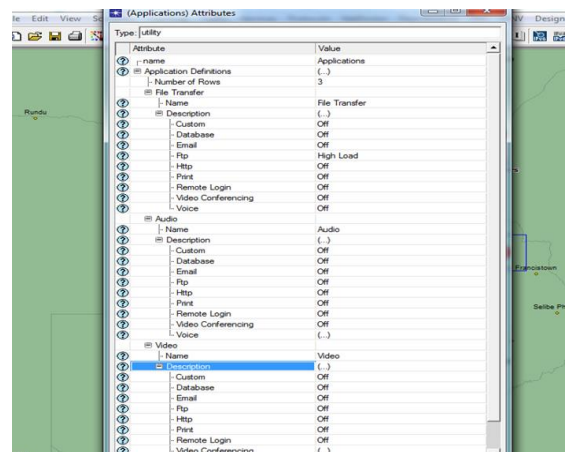
Figure 5. Applications Attributes

Table 2. Summary of Simulation Parameters

		Scenario 1	Scenario 2	Scenario 3
Subscriber stations		**10 kilometres** from the base station	**20 kilometres** from the base station	**30 kilometres** from the base station
Applications Configuration (Client-server)	**File Transfer (FTP)**	High Load ToS Best Effort (0)		
	Audio (VoIP)	PCM Quality Speech ToS Interactive Voice (6)		
	Video Conferencing	High-resolution video ToS (Type of service): Streaming Multimedia (4) **Note:** start-time = Constant(100) for all the applications applications run over TCP/IP and UDP/IP		
WiMAX Configuration parameters	**Type:**	Wireless OFDMA 20 MHz		
	Node Position:	Circular		
	Antenna gain (dBi):	-15		
	Transmission power:	0.5W		
	Duplexing:	TTD		
	Number of Subcarriers:	2048		
Point-to-point link (routers)	**routers with PPP ports:**	4Mbps data rate		
	Default Routing Protocol:	OSPF		
	MPLS	disabled		

6. Proposed Network Model
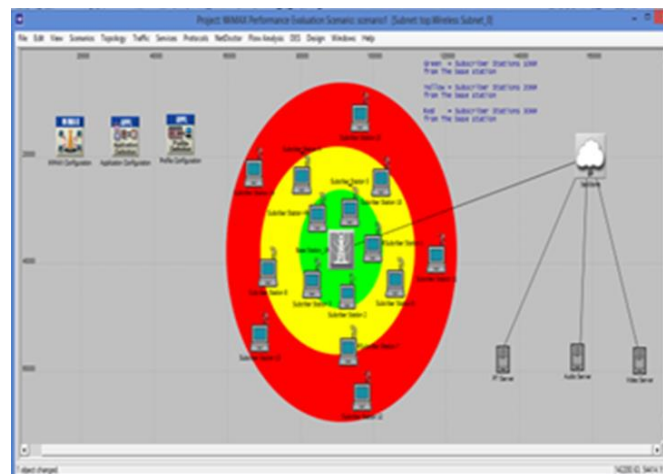
Figure 6. Simulation model

The simulation network topology for this study is shown in Figure 6 and involves the following devices:

i. A base station (Device Name: wimax_bs_ethernet4_slip4_router): A base station sends and receives signals between a transmitting and a receiving point. For example, in mobile/cellular communication, the base station facilitates connection within a given area if the service provider is directly connected.

ii. Three servers (ppp. server model): A server node with server applications running over TCP/IP (Transmission Control Protocol/Internet Protocol) and UDP/IP (User Datagram Protocol), and which supports one underlying SLIP connection.

The data rate of the connecting link determines the operational speed to model file transfer, audio, and video, respectively.

iii. The node (ip32_cloud- node model): An IP cloud supports up to 32 serial line interfaces and models IP traffic at a selectable data rate and routes IP packets through cloud interface to the proper output interface, based on their destination IP addresses. Routing protocols automatically and dynamically create cloud routing tables for directing the transmitted packets.

iv. 15 WiMAX subscriber stations: Subscriber stations are often referred to as CPE (customer premises equipment), as they provide access at the customer side. Five subscriber stations were placed 10 kilometres from the base station for the study, and another five subscriber stations are 20 kilometres from the base station. The last five subscriber stations were 30 kilometres away.

v. The link (ppp_adv point-to-point link): Connects two nodes with serial interfaces (routers with PPP ports) at a selectable data rate. The transmission link connects the base station and the IP cloud with the servers for this study.

7. Results and Discussion

The simulation results depend on the simulation model, which evaluated the performance of WiMAX in scenarios involving subscriber stations placed at various distances from the base station, at 10 km, 20 km, and 30 km.

(**a**)   (**b**)
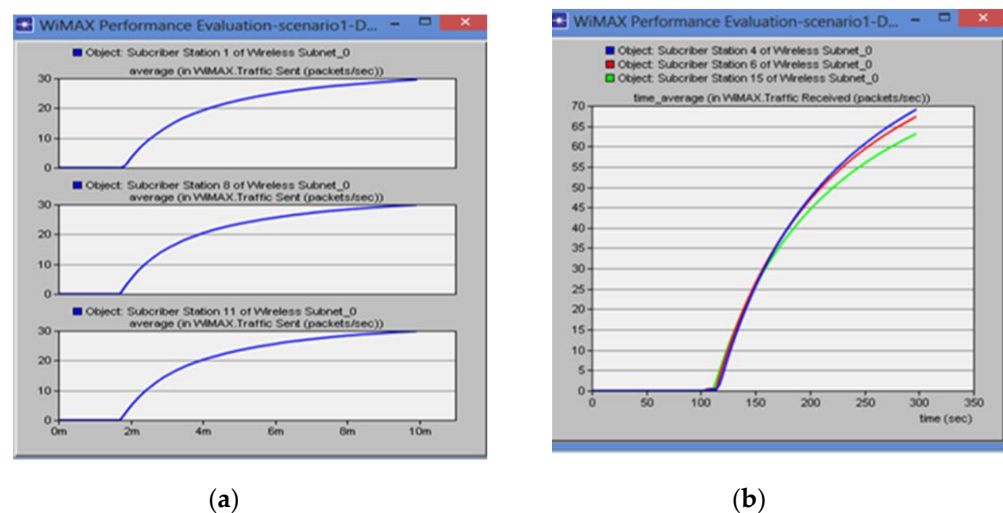
Figure 7. (a) The initial Traffic sent and (b) Traffic Received after simulation

Figure 7 (a) shows Subscriber Station 1, at 10 km, Subscriber Station 8, at 20 km and Subscriber Station 11, at 30 km. Again, the same amount of Y-axis packets sent across the network and the simulation time (X-axis) was equal for the three scenarios.

Figure 7 (b) shows Traffic received; slight variations for the three subscriber stations. For example, packets received at 10 km and 20 km had very slight variations, while packets received at 30 km was significantly different. For 20 km, the rate of packets received widens, implying that distance affects the quality of the packets received and the variations caused by a signal blockage – trees or anything else that blocks the Line of Sight. In rural area transmission, increase use of nodes and lower Traffic to manage variations – the latter is a common feature in rural areas.
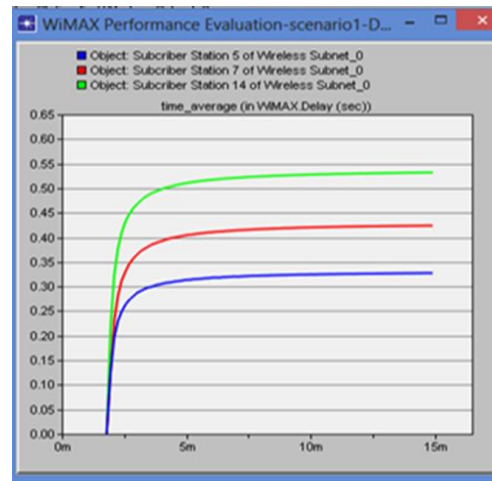
Figure 8. Traffic Delay

Figure 8 presents the average time delay of Traffic from the base station to the three subscriber stations. The delay for the different subscriber stations varied: the subscriber station at 10 km experienced a more negligible time delay, the subscriber station at 20 km experienced an average delay. In comparison, the subscriber station at 30 km experienced the most significant time delay.
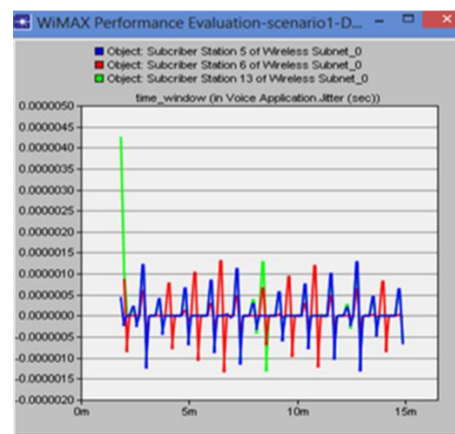
Figure 9. Jitter

In Figure 9, the average time jitter for Traffic over the network upon reaching the three subscriber stations shows that the subscriber station at 30 km experienced jitter, even though it was low. In addition, the subscriber stations at 10 km and 20 km also experienced jitter, though less than the subscriber station at 30 km. Inevitably, expect the jitter at the subscriber station at 30 km, the amount of jitter dropped significantly at the other intervals
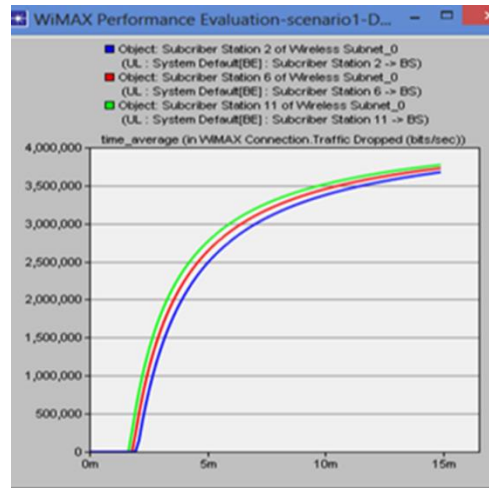
Figure 10. Traffic Dropped

Figure10 presents the Traffic that dropped over the network to the three different subscriber stations. The further the subscriber station from the base station, the more Traffic the network would drop. However, the network consistently retained the packets, which could attribute to the Wireless MAN-FDMA (orthogonal frequency division multiple access) abilities, and the TCP/UDP at the transport layer level. Using TCP/UDP ensures that no packets are lost or dropped by the network.

The simulation results show that metrics balance network deficit with the traffic load to optimise efficiency. For example, the continued simulation showed that the further the subscriber station, the more jitter reduced.

The consistency of the expected performance metric levels from the three subscriber station distance points suggests that the overall performance was better than expected. Observing a delay over longer distances and add more nodes to boost the signal. Also, an apparent characteristic of rural areas, namely, a low population density, means the network may optimise efficiency due to low Traffic.

8.   Conclusions

Literature review indicates that WiMAXIEEE802.16e has a data transfer rate or speed of 70 Mbps, required for online transactions and standard Quality of Experience (Khanduri, Choudhary, & Gupta, 2013). The simulation results indicate that settlements within a radius of 10 to 30 km WiMAXIEEE802.16e can access services. Therefore, the technology requires fewer infrastructure deployment for most cluster villages in Botswana.

On the other hand, using Wi-Fi as a hotspot, the current government initiative, Wi-Fi extends up to 90 metres from the base station and cannot solve the last-mile connectivity challenge.   However, adopting the WIMAXIEEE 802.16e technology to address the last-mile access challenge requires institutional and regulatory frameworks. This study proposes a primary public network to meet universal and affordable connectivity and access. The changes could also force MNOs to diversify services away from voice services, thereby making the network more available to meet clients requiring internet services for voice applications.

Acknowledgements: We would like to thank the Sol Plaatje University for assistance, the Botswana Ministry of Transport and Communications (MTC), Botswana Fibre Network (BoFINet) and Botswana Communication Regulatory Authority (BOCRA) for assisting with information on communication infrastructure about Botswana. We are also thankful to MaSIM and FNAS of the North-West University.

Conflicts of Interest: The authors of this article declare no conflict of interest

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