QUANTITAVE EVALUATION OF UHF TV WHITE SPACES, FOR RURAL BROADBAND CONNECTIVITY

By

Shariwa Madhumbu

Reg Number: R144452V

Submitted in partial fulfilment for the requirement for the degree of Bachelor of Science Honors Degree in Telecommunications

Department of Applied Physics and Telecommunications

Faculty of Science and Technology at the

Midlands State University

Gweru, Zimbabwe

December 2018

Supervisor: Mr. H. Mafukidze

ABSTRACT

With the increase in use of internet access across the world, there has been a shift from classic wired connection technology to the faster and efficient mobile wireless solutions. Zimbabwe as a country is also experiencing this upsurge. However, its hindered by the lack of flexible connection solutions in the densely populated rural areas. A perceived "digital divide" exists between the rural and urban population.

This study seeks to explore a new way of breaking this divide by exploring into Television White Spaces, a relatively untouched technology which makes use of unused frequencies in the RF spectrum. White spaces will occur in the UHF band in Zimbabwe when the country completes its Digital Broadcast migration programme. This study seeks to use methodologies to realize these white spaces and enhance the coexistence for both incumbent and TVWS technologies in the band. This is to aide with the connectivity of the far-fetched rural areas that are traditionally out of reach using orthodox wireless technology.

DECLARATION

I, **Shariwa Madhumbu**, hereby declare that I am the sole author of this thesis. I authorize the Midlands State University to lend this thesis to other institutions or individuals for the purpose of scholarly research.

Signature………………………………… Date ………………………………………

APPROVAL

This dissertation/thesis entitled "Quantitative Evaluation of UHF TV White Spaces in Zimbabwe, For Broadband Connectivity" by **Shariwa Madhumbu** meets the regulations governing the award of the degree *BSc Telecommunications Honors* of the Midlands State University, and is approved for its contribution to knowledge and literal presentation.

Supervisor ………………………………………………………….

Date ……………………………………………………………………

ACKNOWLEDGMENTS

Firstly, my utmost gratitude goes to the Lord Almighty for His mercies and giving me the strength, knowledge and ability to undertake this degree. I am forever indebted to my supportive, caring and loving family. To my rock, my mother, I owe my heartfelt gratitude. A special shout-out goes to my friends, my virtual support system, for their invaluable support..

Further mention is extended to the Department of Applied Physics & Telecommunications members of staff for their guidance during the degree programme. Special mention to my supervisor, Mr. Harry Mafukidze for his guidance and assistance in my conducting this research and without whom, this dissertation would not have been possible. Your contributions are all humbly appreciated

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Introduction

Amid the rising demand for bandwidth, researchers around the world have measured and studied the occupancy of spectrum in different countries. These measurements suggest that except for the spectrum assigned to services like cellular technologies, and the industrial, scientific bands, most of the allocated spectrum is heavily underutilized. Among all the unutilized portions of the frequency spectrum, white spaces in the Ultra High Frequency (UHF) Television (TV) bands have been of particular interest owing to the superior propagation characteristics as compared to the higher frequency bands.

The current global move to switch from analogue to digital TV has opened up an opportunity for the reallocation of the spectrum. In one way, spectrum bands once used for analogue TV broadcasting will be completely cleared, leaving a space for deploying new licensed wireless services. Digital television technology is known to geographically interleave spectrum bands to avoid interference between neighbouring stations, leaving a space for deploying new unlicensed wireless services.

Zimbabwe is no stranger to the current digital migration trend. The complete transition from analogue to the digital TV was planned in Zimbabwe for 2015, however several delays have dogged the project which has in turn slowed down progress. Ideally, after the intended analogue switch-off, the spectrum 490MHz to 890MHz (UHF TV channel frequency channels), will be entirely dedicated broadcast. However, in this spectrum, not all channels are occupied at each location, due to coverage limits in network planning. These locally unused channels are called TV white space (TVWS).

1.2 Background

Zimbabwe, as a developing country in the 21st century is undergoing enormous strides in its technology sector, as ICTs continue to characterise societies, contributing to national development by supporting economic evolution and social development. Obtaining access to effective and maintainable ICT infrastructure has thus turn out to be a major goal worldwide, particularly considering the dynamic role that ICTs play across all expanses of human life, in areas like Science, Education, Financial markets, Security, Health, and Civil protection, Business development, Entertainment and Media, amongst others.

Due to the current efforts to attain this objective, a sheer escalation in the demand for bandwidth for communication systems is experienced, as is the shift from the preference of fixed wire mediums to mobile technologies. This increase results in the predictable burden on the source of the resource, radio spectrum, the essential resource to allow wireless technologies to transmit and receive data. Development of alternate methods for addressing the spectrum crisis and also to optimize the use of the available spectrum is vital for all the regulatory boards in respective nations

This study explores a mode of spectrum utilization that is finding popularity world over is the use of TV White Spaces for communications systems. TV white spaces (TVWS) are ―portions of spectrum left unused by broadcasting, also referred to as interleaved spectrum‖. The TV White spaces have excellent propagation characteristics and hence are a huge attraction worldwide for wireless communications. Countries like US, UK, Canada & Singapore have already formulated regulations for the usage of TV White Spaces for wireless communications (fixed and mobile), and many others like Japan, Hong Kong etc. are actively considering to do the same. This study attempts to cover the TV White Space technology, the global situation for the use of TVWS, the relevant standards to the TVWS system, the governing framework and other applicable points. In this paper, we explore, assess and propose TV white space implementation architecture and metrics in Zimbabwe to provide internet connectivity in rural areas.

1.3 Problem Statement

In Zimbabwe, two out of three people in the do not have access to internet [31]. More than half the population in the country lives in rural areas with hardly any access to broadband. It is expensive to lay fibre optic cable in rural and remote areas with low population density. Hence, except for direct coverage by satellite where cost-effective and low latency solutions are still developing, wireless is the only practical solution. The country's traditional wireless carriers have focused on urban areas with high population density. Since Zimbabwe is a third world developing country, traditional technologies have been unable to provide large area wireless coverage under non-line-of-sight (NLoS) conditions present in rural area to build successful and viable business models. This has culminated into a "digital divide" [32].

The country's decision to implement Analog to digital TV transition has provided an opportunity to bridge this digital divide. This is because one traditional analog TV channel typically allows up to 5 standard definition digital television (DTV) signals to be transmitted. Excess spectrum is often called the "digital dividend" and it can be used to provide broadband access as long as no interference is caused to primary users of the bands.

In addition, TV Channels in VHF/UHF bands have highly favourable propagation features for long-distance reach. TV Band White Spaces can provide more than ten times the reach of the wireless access solutions in other bands that are above 1 GHz. Wireless communication networks are the most feasible and economically viable broadband solution for rural areas characterized with low teledensity and lack of fixed-line telecommunications infrastructure. However, wireless networks rely on the availability and affordability of radio frequency (RF) spectrum, which is a scarce natural resource. While few studies claim shortage of usable RF spectrum [25], many studies [26], [27] assert that the utilization of the licensed frequency bands varies from 10% to 85% depending on the geographical location and time of the day. There is a growing acknowledgement that dynamic spectrum sharing, especially on TV white spaces (TVWS), is impending to increase the availability and ubiquity of broadband access thereby addressing the digital divide in the country.

1.4 Justification

The study is aimed at improving the overall Broadband Internet experience in the rural areas. Implementation of the TVWS system in the designated areas will help both users and service providers in several ways. Chief of the advantages for the users being their ability to access low cost Broadband connectivity, something which was foreign to them. The Service providers will benefit from their brands and products tapping into a new market and geographical locations, thereby enhancing organizational growth. The Quantification of TV White Spaces is necessary process which makes the study aware of how much spectrum space is available at each site, as well as evaluating the technical aptitude of the proposed network to provide broadband access. Furthermore, it is also very much necessary to examine the degree to which the TVWS broadband transmissions would be able to co-exist with Digital Television transmissions without disturbing TV reception.

1.5 Objectives of study

The empirical quantification of the available TV white space in Zimbabwe is presented. The quantification utilizes existing methods in the literature, namely the Protection Boundary [29], and the technical specifications of the Federal Communications Commission [30].

Motivated by underutilization of UHF TV band spectrum, the study is aimed at attaining the following objectives.

1.5.1 Main Objective

- To use available mechanisms to evaluate, assess and quantify the amount of available TV White Space in certain locations in rural Zimbabwe.

1.5.2 Minor Objectives

- To establish methods for the existing DTT signals to coexist in the UHF band with the TVWS services.
- To conjure up possible gaps that can be filled up with this imminently available spectrum. In this case, Rural Broadband connectivity.
- To test and establish the various pros and cons of using the TV white spaces in the UHF band so as to recommend to current mobile infrastructure owners to implement them.

1.6 Dissertation Layout

The study is organized as follows, The Introduction, Chapter 1, looks at all the available pre-study material such as the introduction, background of the study, justification, research objectives of TV White Space Quantification.

Chapter 2 presents mainly on the theoretical aspects that surround TV White Space Quantification, which include the Radio Spectrum, Frequency Planning and the current state of the spectrum in Zimbabwe.

Chapter 3 will focus on the methods to be utilised in the study, while results and analysis are presented in Chapter 4.

Chapter 4 also proposes the broadband system's architecture and the variables surrounding it.

Chapter 5 completes the study by concluding, discussing the study and also describing the future work that may need to be considered for further developments in relation to Zimbabwe's UHF TV Spectrum and TV White Spaces.

CHAPTER 2

LITERATURE REVIEW & THEORETICAL ASPECTS

2.1 Introduction

This chapter presents all the necessary theoretical concepts which are essential in apprehending the problem and the suggested solution cited in this study. The literature review presents the basic concepts and developments of TV White Spaces. Basically the literature review is an objective, critical summary of available research literature, which is applicable to the current study. Its resolution is to generate familiarity with current thinking and research in the field of TVWS.

2.2 The Radio Frequency Spectrum

The radio frequency spectrum is the portion of the electromagnetic spectrum which houses frequencies from 3Hz to 3000GHz. Electromagnetic waves in this frequency range are called radio waves [12]. Distinct segments of the RF spectrum are allotted by the ITU for different applications and technologies. Usually, parts of the RF spectrum are auctioned or licensed to operators of private transmission services like MNOs and Broadcasters. Ranges of allocated frequencies are frequently stated by their provisioned use. Since spectrum is a fixed resource which is in demand by an increasing number of users, it has become progressively congested in recent decades [7]. That is when the need to exploit it more efficiently is driving contemporary telecommunications innovations, arose.

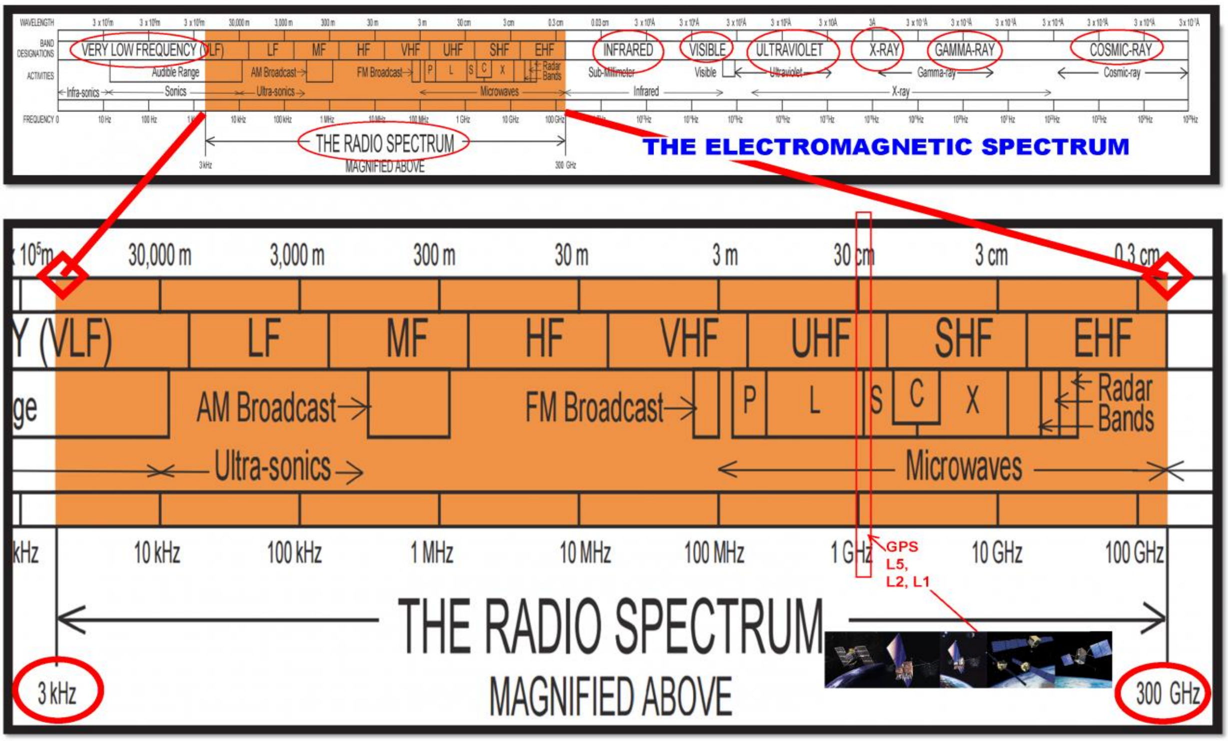

Fig 2.1 A graphical representation of the RF Spectrum

2.2.1 Ultra High Frequency band

Ultra high frequency (UHF) further depicts the segment of radio frequencies in the range between 300MHz and 3GHz. UHF radiation is the least affected by environmental factors, hence it is most commonly used for broadcasting [5]. UHF waves possess very strong directivity, though it comes at the expense of increased receiver error rates.

UHF is extensively used for data transmission owing to its short wavelength and high frequency. Since the size of a receiver antenna is directly proportional to the size of the waves, UHF antennas are characteristically short and stout. The study will however be centrally focused on the lower part of the UHF Band, ranging from 300MHz to 800MHz, this being often labelled as the “Broadcast Segment” of the entire UHF Band. In Zimbabwe, the current TV signal is operating in the VHF band, at around 210Mhz to 290MHz, nationwide.

2.2.2 UHF Propagation Characteristics

UHF Radio waves travel almost entirely by line-of-sight propagation (LOS) and ground reflection. They are however known to be blocked by hills and large buildings while transmission through building walls is strong enough for indoor reception. Wavelengths of UHF waves are comparable to the size of buildings, trees, vehicles and other common objects which implies that reflection and diffraction from these objects can cause fading due to multipath propagation, especially in urban areas [12]. Furthermore, atmospheric moisture attenuates the strength of UHF signals over long distances, and the attenuation increases with frequency but sometimes when conditions are right, UHF radio waves can travel long distances by tropospheric ducting as the atmosphere warms and cools through the day. UHF TV signals are usually more affected by moisture than lower bands, such as VHF TV signals. UHF transmission is limited by the visual horizon to 50–70 km and often to shorter distances by local terrain. It allows frequency reuse, that is the same frequency channels to be reused by in adjoining geographic areas [3].

2.2.3 Applications of the UHF Band

In many parts of the world, most of the UHF bandwidth has been allocated to land mobile, trunked radio and mobile telephone use. Primarily the band is used for television broadcasting, cell phones, satellite communication including GPS, personal radio services including Wi-Fi and Bluetooth, walkie-talkies and cordless phones [6]. When DTT came around, UHF television broadcasting satisfied the demand for additional over-the-air television channels in urban areas. UHF channels are now the practically permanent home for digital television.

Other minority UHF spectrum allocations include land mobile radio systems for commercial, industrial, public safety, and military purposes. Major telecommunications providers have deployed voice and data cellular networks in the UHF range [6]. Which in turn permits mobile phones and mobile computing devices to be connected to the public switched telephone network and public Internet.

2.3 Radio Spectrum in SADC

The Southern African Development Community (SADC) is a inter-governmental Regional Economic Community comprising 16 Member States; Angola, Botswana, Comoros, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia and Zimbabwe. The member states share various protocols and Spectrum management is one of them. There is need for harmonisation when it comes to the Radio Spectrum in the region [15], [16]. Harmonisation in using the radio frequency spectrum is vital to guarantee the following:

1. Economies of scale in the radio equipment
2. Interoperability between systems and networks
3. Facilitating frequency coordination between countries
4. Establishing international systems and networks and to enable roaming between networks.

Preferably spectrum harmonisation should be conventional worldwide; however, due to the elevation and fortification of regional markets and alterations in the use and application of the radio frequency spectrum, it is rarely achieved. The SADC authorities convened and resolved to draw up the SADC Frequency Allocation plan. Its purpose is to create a framework for the harmonisation across SADC on the use of the radio frequency spectrum. It is, however, known that presently the utilisation of radio frequency spectrum bands in SADC countries are different due to, amongst others, legacies in system deployments, different time scales for the introduction of new technologies, different services and technology requirements as well as different bandwidth requirements. While it isn't possible to align radio frequency spectrum use over all frequency bands among all states, it is however plain that harmonisation already exists in many frequency bands in SADC [15]. The harmonisation is protracted to as many frequency bands as possible within SADC via this regional frequency allocation plan. This in turn spills into the study since the Government of Zimbabwe adheres to and aligns itself with the SADC Frequency Allocation Plan.

2.4 Radio Spectrum in Zimbabwe

The Postal and Telecommunication Regulatory Authority of Zimbabwe (POTRAZ) was given a mandate by the Zimbabwe government to control the country's IT sector through developing an institutional framework for telecommunications. This indirectly means that POTRAZ is responsible for the Radio Spectrum in Zimbabwe [16], amongst other things. POTRAZ has made reasonable inroads in executing its mandate in liberalizing the telecoms sector which saw the regulator generating a level playing field for the players in the sector. The regulator also delivered the Zimbabwe National Frequency Allocation Plan (ZNFAP) which will be adopted in assigning radio frequencies to telecom services and operators. The regulator has allocated several bands of frequencies for Broadcasting purposes [16]. Below are extracts from the ZNFAP, which highlight some of the major bands given to the broadcasters. The heading of the Table includes five columns. The first column of the table indicates the frequency band for a particular allocation. The second, third and fourth columns are allocation to radio services in ITU Region 1, SADC and Zimbabwe respectively. The fifth column indicates the main utilization in Zimbabwe [16].

Frequency band (MHz)	**ALLOCATION TO RADIO SERVICES**			**ZWE Main Utilisation**
	ITU Region 1	**SADC**	**Zimbabwe**	
47-50	BROADCASTING 5.162A 5.163 5.164 5.165 5.169 5.171	LAND MOBILE 5.164 5.165	LAND MOBILE	PMR CT0 Cordless Telephony MTx (49.67-49.97 MHz)
50-54	BROADCASTING 5.162A 5.163 5.164 5.165 5.169 5.171	AMATEUR 5.164 5.165 5.169	AMATEUR 5.169	AMATEUR
54-68	BROADCASTING 5.162A 5.163 5.164 5.165 5.169 5.171	MOBILE except aeronautical mobile 5.164 5.165 5.171	FIXED MOBILE except aeronautical mobile 5.171	FIXED AND MOBILE in accordance with 5.171
68-74.8	FIXED MOBILE except aeronautical mobile 5.149 5.175 5.177 5.179	MOBILE except aeronautical mobile 5.149 SADC4	MOBILE except aeronautical mobile 5.149	PMR and/or PAMR
74.8-75.2	AERONAUTICAL RADIONAVIGATION 5.180 5.181	AERONAUTICAL RADIONAVIGATION 5.180	AERONAUTICAL RADIONAVIGATION 5.180	AERONAUTICAL RADIONAVIGATION Instrument Landing System (ILS) Marker beacons (75 MHz)
75.2-87.5	FIXED MOBILE except aeronautical mobile 5.175 5.179 5.187	MOBILE except aeronautical mobile	FIXED MOBILE except aeronautical mobile	PMR and/or PAMR
87.5-100	BROADCASTING 5.190	BROADCASTING	BROADCASTING	FM SOUND BROADCASTING
100-108	BROADCASTING 5.192 5.194	BROADCASTING	BROADCASTING	FM SOUND BROADCASTING

Fig 2.2 Frequency Allocation in Zimbabwe from 47MHz to 108MHz

Frequency band (MHz)	ALLOCATION TO RADIO SERVICES			ZWE Main Utilisation
	ITU Region 1	SADC	Zimbabwe	
161.9625-161.9875	FIXED MOBILE except aeronautical mobile Mobile-Satellite (Earth-to-space) 5.228F 5.226 5.228A 5.228B	FIXED MOBILE except aeronautical mobile Mobile-Satellite (Earth-to-space) 5.228F 5.226 5.228A 5.228B	FIXED MOBILE except aeronautical mobile Mobile-Satellite (Earth-to-space) 5.228F 5.226 5.228A	PMR in accordance with 5.226 Aircraft based search and rescue in accordance with 5.228A
161.9875-162.0125	FIXED MOBILE except aeronautical mobile 5.226 5.229	FIXED MOBILE except aeronautical mobile 5.226 5.229	FIXED MOBILE except aeronautical mobile 5.226	PMR in accordance with 5.226
162.0125-162.0375	FIXED MOBILE except aeronautical mobile Mobile-Satellite (Earth-to-space) 5.228F	FIXED MOBILE except aeronautical mobile Mobile-Satellite (Earth-to-space)5.228F 5.226 5.228A 5.228B 5.229	FIXED MOBILE except aeronautical mobile Mobile-Satellite (Earth-to-space) 5.228F 5.226 5.228A	PMR in accordance with 5.226
162.0375- 174	FIXED MOBILE except aeronautical mobile 5.226 5.229	FIXED MOBILE except aeronautical mobile 5.226 5.229	FIXED MOBILE except aeronautical mobile 5.226	PMR in accordance with 5.226 Radio Aids for the deaf
174-223	BROADCASTING 5.235 5.237 5.243	BROADCASTING 5.237	BROADCASTING	BROADCASTING Broadcasting (174-214 MHz) T-DAB (214-230 MHz)
223-230	BROADCASTING Fixed Mobile 5.243 5.246 5.247	BROADCASTING	BROADCASTING	BROADCASTING TV Broadcasting (174-214 MHz) T-DAB (214-230 MHz)
230-235	FIXED MOBILE 5.247 5.251 5.252	BROADCASTING 5.252 SADC8	BROADCASTING 5.252	BROADCASTING

Fig 2.3 Frequency Allocation in Zimbabwe from 161MHz to 235MHz

Frequency band (MHz)	ALLOCATION TO RADIO SERVICES			ZWE Main Utilisation
	ITU Region 1	SADC	Zimbabwe	
235-238	FIXED MOBILE 5.111 5.252 5.254 5.256 5.256A	BROADCASTING 5.252 5.254 SADC9	BROADCASTING 5.252 5.254	BROADCASTING
238 - 246		MOBILE 5.111 5.254 5.256 SADC9	MOBILE 5.111 5.254 5.256	International aircraft Distress Frequency (243 MHz) 243.05-246.00 MHz Low-power devices
246 - 254		BROADCASTING 5.252 5.254 SADC9	BROADCASTING 5.252 5.254	BROADCASTING
254 -267		MOBILE 5.254 SADC9	MOBILE 5.254	
267-272	FIXED MOBILE Space operation (space-to-Earth) 5.254 5.257	FIXED MOBILE 5.254 5.257	FIXED MOBILE 5.254 5.257	FIXED MOBILE
272-273	SPACE OPERATION (space-to-Earth) FIXED MOBILE 5.254	SPACE OPERATION (space-to-Earth) FIXED MOBILE 5.254	SPACE OPERATION (space-to-Earth) FIXED MOBILE 5.254	FIXED MOBILE
273-312	FIXED MOBILE 5.254	FIXED MOBILE 5.254	FIXED MOBILE 5.254	FIXED MOBILE

Fig 2.4 Frequency Allocation in Zimbabwe from 235MHz to 312MHz

Frequency band (MHz)	ALLOCATION TO RADIO SERVICES			ZWE Main Utilisation
	ITU Region 1	SADC	Zimbabwe	
470-606	BROADCASTING 5.149 5.291A 5.294 5.296 5.300 5.304 5.306 5.311A 5.312 5.312A	BROADCASTING Mobile 5.296	BROADCASTING Mobile 5.296	BROADCASTING
606 - 614		BROADCASTING RADIO ASTRONOMY 5.304 Mobile 5.296 5.149	BROADCASTING RADIO ASTRONOMY 5.304 Mobile 5.296 5.149	BROADCASTING RADIO ASTRONOMY
614 - 694		BROADCASTING Mobile 5.296 5.311A	BROADCASTING Mobile 5.296 5.311A	BROADCASTING
694-790		BROADCASTING MOBILE except aeronautical mobile 5.312A SADC12 5.311A	BROADCASTING MOBILE except aeronautical mobile 5.312A SADC12 5.311A	Zimbabwe plans to implement IMT in this band immediately after WRC-15.

Fig 2.5 Frequency Allocation in Zimbabwe from 470MHz to 108MHz

The above extracts give a vivid picture of the spectrum allocation in VHF and UHF bands with respect to Broadcasting.

2.5 Digitalization

As mentioned earlier, Zimbabwe is involved in worldwide digital migration trend. The projected transition from analogue to digital transmission has been slowed down, but is almost complete. The expansion of technology and improvements in terrestrial TV broadcasting standards has made DVB-T2 technology more popular because of its advantages, namely high quality content (audio and video), interactivity, integration capability, scalability, signal robustness and more bandwidth.

The Government of Zimbabwe has placed high emphasis on digital broadcasting as one of the key agendas for national development [17]. Digital broadcasting brings with it several technological advantages with respect to increased number of channels, new advanced services, spectrum efficiency as well as improved picture and sound quality. To achieve this, Government initiated the *Zimbabwe Broadcasting Digitalization* project, to establish a digital TV broadcasting system for the DVB-T2 broadcasting network and also provide FM broadcasting solution. The Proposed solution involved setting up 48 transmitter sites around Zimbabwe. The current Analogue transmission has its various drawbacks and is going to be phased out [2], [6]. The Analogue system operates as a SFN in the VHF band. The signal is distributed by Point to Point RF Links. The current operating frequency is around 170MHz to 210MHz nationwide.

The Digital Terrestrial System will offer a different signal path. The National Headend is responsible for broadcasting to the several DTT sites. Video signals are transcoded into MPEG-4 and then multiplexed. The multiplexer output is sent to the uplink system which is a DVB-S2 based Ku-band Satellite uplink system. The same satellite, owned by Eutelsat, is used as the program distribution link. The Satellite link beams down the channels to each transmitter site.

The Transmitter sites have Downlink Dishes which receive the Satellite signal and its processed through to the UHF Antennas which are responsible for the Last mile transmission. The illustration below shows the DTT System setup, showing the key components, The headend, the satellite system and the 48 Transmitter Sites [17].

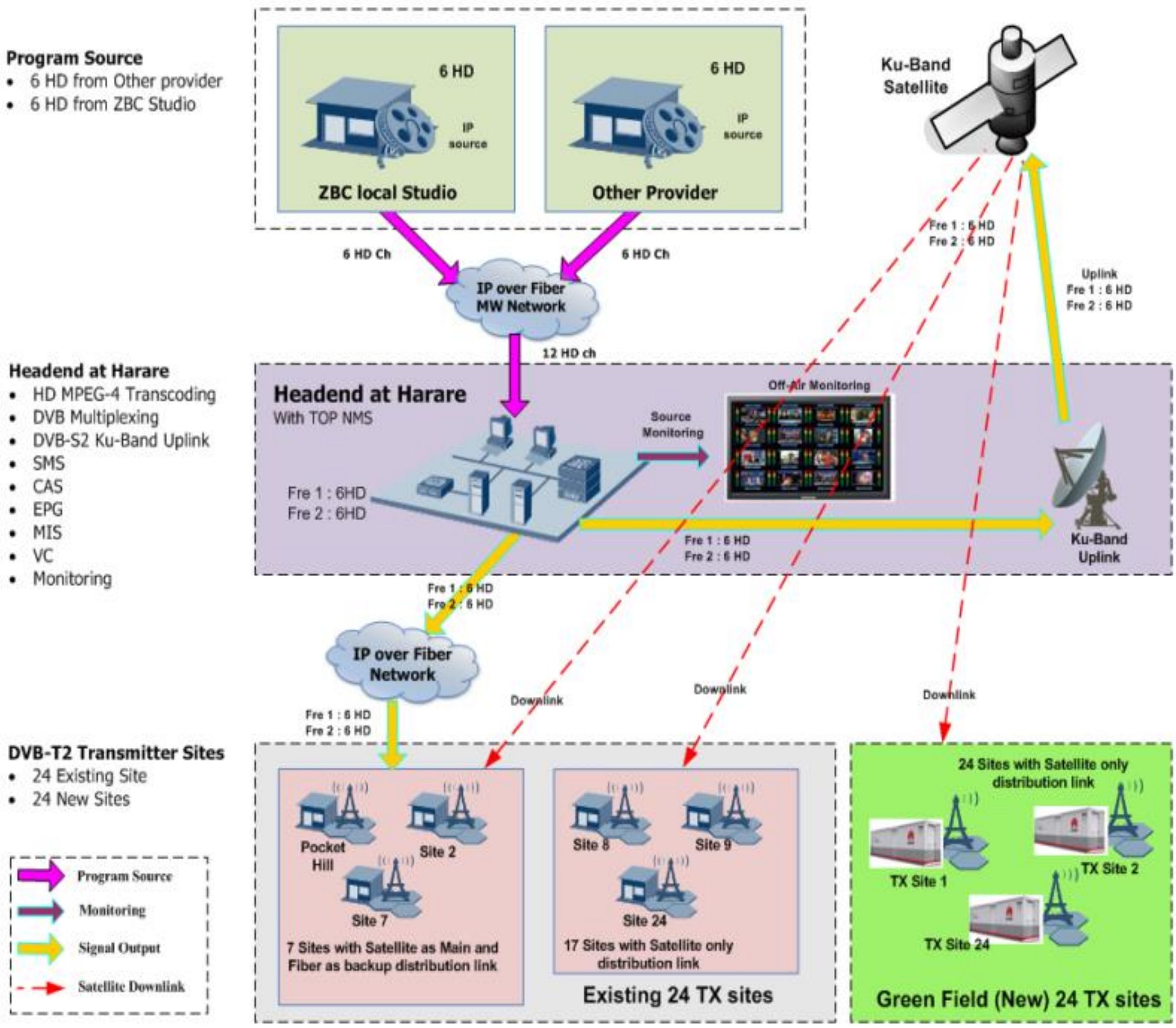

Fig 2.6 The DTT System in Zimbabwe

Superlatively, after the analogue switch-off, the spectrum 470MHz to 790MHz (UHF TV channel frequency channels), will be entirely cleared for broadcast. The system will only utilise two 8MHz channels at each site, for the DVB-T2 Broadcasting. One band for broadcasting the TV Channels and the other for backup or redundancy. This leaves each site with large amounts of unused, good UHF bandwidth [14], [17].

Site name	Frequency (MHz)	Antenna Height (m)	Transmitter power (W)	Antenna type
Bakasa	482	100	1100	4*4*4*4
Beitbridge	474	120	1100	4*4*4*4
Bikita	474	100	1100	4*4*4*4
Bindura	474	100	1100	4*4*4*4
Binga	482	60	1100	4*4*4*4
Buhera	602	100	1100	4*4*4*4
Bulawayo	498	100	2600	6*6*6*6
Chinhoyi	594	100	1100	4*4*4*4
Chiredzi	626	100	1100	4*4*4*4
Chivhu	570	100	1100	4*4*4*4
Gokwe	474	100	1300	6*6*6*6
Gutu	490	100	1100	4*4*4*4
Gwanda	626	100	1300	6*6*6*6
Gwendingwe	682	120	1100	4*4*4*4
Gweru	482	100	1300	6*6*6*6
Harare	618	100	2600	6*6*6*6
Hwange	474	100	1100	4*4*4*4
Insiza	610	100	1100	4*4*4*4
Insiza Junction	To be used as SFN for gap filling		1100	4*4*4*4
Kadoma	602	100	1100	4*4*4*4
Kamativi	626	120	1100	4*4*4*4
Kariba	618	55	1100	4*4*4*4
Karoi	626	120	1100	4*4*4*4
Kenmaur	618	120	1100	4*4*4*4
Kotwa	562	60	1100	4*4*4*4
Kwekwe	490	100	1100	4*4*4*4
Mapengola	498	100	1100	4*4*4*4
Mashava	To be used as SFN for gap filling		1100	4*4*4*4
Masvingo	610	79	1100	4*4*4*4
Matopos	618	100	1100	4*4*4*4
Mberengwa	To be used as SFN for gap filling		1100	4*4*4*4
Mt Darwin	594	120	1100	4*4*4*4
Mudzi	602	120	2600	6*6*6*6
Mutare	626	49	2600	6*6*6*6
Mutoko	482	100	1100	4*4*4*4
Mutorashanga	490	100	1100	4*4*4*4
Mvuma	522	100	1100	4*4*4*4
Ngezi	618	60	1100	4*4*4*4
Nkai	626	100	1100	4*4*4*4
Plumtree	506	120	1300	6*6*6*6
Rukotso	682	120	1300	6*6*6*6
Rutenga	490	100	1100	4*4*4*4
St Alberts Mission	530	100	1100	4*4*4*4
Victoria Falls	618	57	1300	6*6*6*6
Wedza	498	100	1100	4*4*4*4
West Nicholson	490	100	1100	4*4*4*4
Zvishavane	474	100	1100	4*4*4*4
Susamoya	UC	100	1100	4*4*4*4

Fig 2.7 Table showing the centre frequencies of some of the finished sites

The tables above depict the centre frequencies of some of the sites that are already operational. The centre frequency is the middle frequency of an 8MHz band, taking for example the tower at Gweru is operating at 482MHz, that is to say, it is using the range 478 – 486 MHz to operate. Also at Gweru, another 8MHz band is in use for backup, but the frequency is not given. It's also worth noting that the DTT System is a MFN which is actually occupying the frequencies in the range of 470MHz to 680MHz.

2.6 Television White Spaces

This entire study is based on 'White space' which technically, is a label designating a fragment of the spectrum, which is accessible for a radiocommunication application (service, system) at a given time in a given geographical area on a non-interfering / non-protected basis with regard to other facilities with a higher priority on a national basis. TVWS are of a specific interest owing to the good propagation properties at VHF and UHF frequency bands, and due to availability of underused spectrum, confirmed by multiple [1] - [8] studies. Critical to this study, the UHF band is known to exhibit excellent outdoor and indoor coverage and non-line-of-sight propagation properties.

A white space device (WSD), is a secondary user of spectrum. For the WSD to operate without interfering with primary users, protection criteria are obligatory. For a network of such devices to function, supplementary criteria may be required. A WSD can either be a base station (BS) or a terminal radio (TR).

2.6.1 Theory behind White Space

The ITU report "Digital Dividend 3: Insights for spectrum decisions", states that TV white spaces are "*portions of spectrum left unused by broadcasting, also referred to as interleaved spectrum*". Widely, TVWS are also referred to as those currently unoccupied portions of spectrum in the terrestrial television frequency bands in the VHF and UHF TV spectrum (be it analogue or digital, generally in the UHF band) [4].

These TV spectrum "gaps", with valuable propagation properties characteristic to UHF spectrum have been recognized in some administrations as a substitute for providing commercial wireless services other than broadcasting [7].

Some of the wireless technologies being explored in TVWS are low-power, machine-to-machine communication devices and low-power wireless broadband applications, capitalizing on the longer coverage ranges achievable with UHF spectrum. Radio signals in the UHF TV band can cover larger areas than Wi-Fi signals for the same power. These signals are also better at penetrating obstacles such as foliage and walls. Rural areas in developing countries are likely to have an abundance of TVWS spectrum because TV service utilization is low. In Zimbabwe there is currently one TV service, that is ZTV, After Digital Migration, there will be 12 TV Services [17]. TV White Space gets its name from the fact that it falls in the spectrum range of 470-890 MHz (ITU- Region 3 Frequency Allocations) which is the band allocated mainly for Broadcasting as the primary service.

There are different ways in which TVWS can arise at any given location. The amount of spectrum available in the form of TVWS can vary significantly across different locations and will depend on various factors, including:

- Geographical features
- The level of interference potential to the TV broadcasting service
- TV coverage objectives and related planning
- TV channels utilization.

The availability of TVWS can be mainly categorized as:

i) Frequency

The idle channels of a TV band plan in some geographical areas due to interference avoidance techniques like employing guard bands

ii) Height:

Defines the accessibility of TVWS at a assumed area in terms of the height of the TVWS transmission site and its antenna height, in relation to surrounding TV broadcasting coverage reception

iii) Space:

Geographical areas that are outside the current TV coverage and therefore no broadcasting signal is currently present. Also, those geographical separation areas between locations using the same TV channels.

iv) Time domain:

TVWS could become available when a broadcasting emission is off-air; hence the licensed broadcasting transmitter is not using the assigned frequency channel during a specific period of time and so making it available for use as TVWS on non-interference basis.

However most of these criteria do not apply currently in Zimbabwe since there is only one broadcaster, and also after Digitalization, the 12 Channels will be monitored and managed by the same organization. Unlike in other countries with privatised TV stations [16], [17].

2.7 Previous Studies

There have been many studies and test for TV White Space technologies in Southern Africa and the world over. The studies are all on effective use of the spectrum by employing other technologies, to offer several services in the existing TVWS frequencies.

2.7.1 Malawi TVWS Trials

The increasing demand for wireless data transmission in Malawi imposed the search for alternatives to the current spectrum exploitation schemes. The use of currently vacant spectrum allocated to TV broadcast, poised at alleviating the spectrum crunch while opening the path for dynamic spectrum access was explored [18].

An assessment of the performance of secondary systems in realistic situations would ultimately help to measure the usability prospects for TVWS-driven technologies. In Malawi, the partnership between the regulator and the University of Malawi-Chancellor College worked to develop a performance analysis of the network in December 2013. The deployment of the pilot was done in September 2013 in partnership with the International Centre for Theoretical Physics (ICTP) from Trieste, Italy. The goals for the Malawi TVWS Pilot are similar to that of the Cambridge Trial [10] that is, to help industry understand the capability of TV white spaces to serve a wide range of applications, through key factors such as the coverage and performance that can be achieved.

The Malawi TVWS network topology was a typical star configuration, with the base station as hub and the CPEs as clients. The base station is located in a 40 m tower that accommodated the FM broadcasting, WSD antennas and a 5 GHz point-to-point wireless link to the Internet Service Provider that offers the connectivity to the outside world. The CPEs used Standard UHF Receiver Antennas [18].

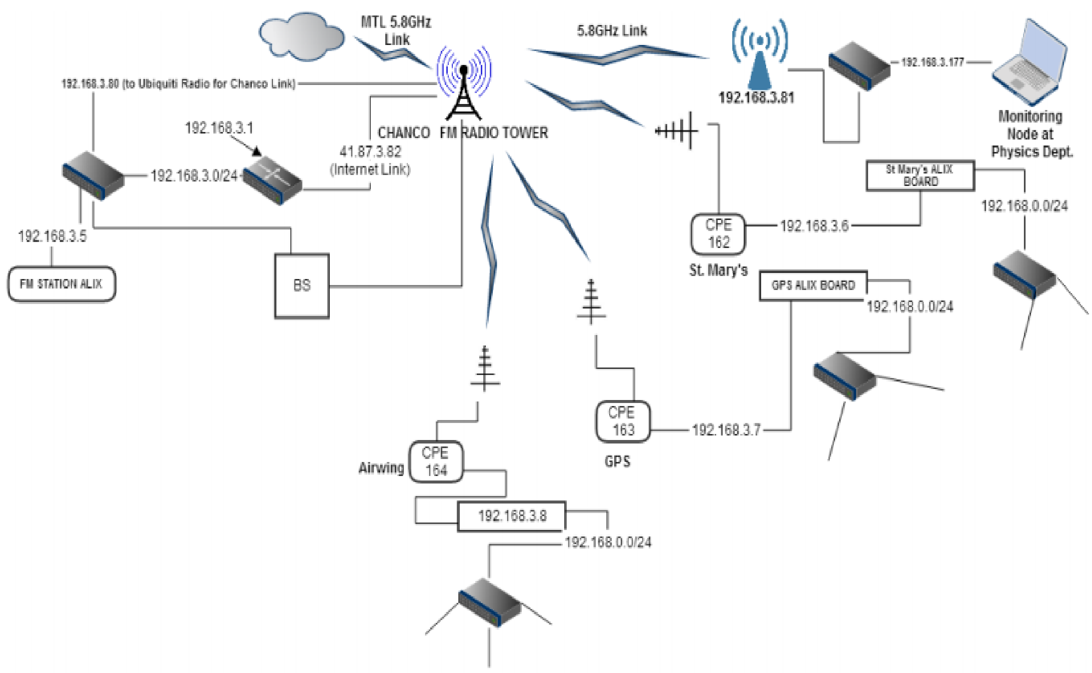

Fig 2.8 The Malawi TVWS Network Topology

Spectrum usage measurements were carried out alongside other data network measurements like latency and throughput. After determining the white space and setting up the network and testing it, the engineers concluded that the network had been a positive outcome with significant impact in the context of a developing country [18]. Further study on the network performance was carried out in order to compare the network resilience both in dry and rainy weather seasons.

2.7.2 Limpopo Rural TVWS Project

The Limpopo TVWS project used TVWS to provide broadband Internet to five schools which are within 10km radius of the University of Limpopo (UL) in the rural Mankweng Township. Each of the participating schools was donated 31 tablets, an overhead projector and smart phone to enable e-learning delivery. The goal was to test and setup a network that provides Internet connectivity and more importantly e-learning to the five rural schools which never had access to internet. Broadband Internet access was provided using the TVWS technologies [19]. TVWS transceivers were installed at the trialists' premises and they were pointed in the direction of the University, where a white space base station mast was erected. The network operates in a point-to-point configuration whereby each one of the CPEs is directly linked with its own BS. The point-to-point network layout was mainly considered to maximize the throughput of the TVWS connections for each of the schools but is suboptimal economically and in terms of usage of spectrum. Each CPE is capable of transmitting up to 26 dBm of EIRP, which is 20 dBm by WSD plus 6 dBi due to the antenna gain. The CPE is then connected to the router board and Wi-Fi access point which provides wireless local area network (WLAN) to be accessed by tablets, laptops and smart phones at each school.

Each school is designed to provide Internet landing speed of 10 Mbps with a target TCP throughput per schools of between 5 and 10 Mbps. The several different types of field measurements were completed to consider key aspects of white space network operation, and possible interference on the reception of TV broadcasting [19]. Ongoing tests on this system show that desirable and favourable conditions of the spectrum has opened up the system to possible expansion. The project is viewed as a major success [20].

Fig 2.9: Limpopo TVWS Network Layout showing distances from the BS at UL library to each CPE site and the TV channels used per CPE

2.8 Modulation Theory

The mentioned transmitters that will broadcast in the UHF Band will use 64bit Quadrature Amplitude modulation. Modulation is defined as the process of varying one or more properties of a periodic waveform, the carrier signal, with a modulating signal that typically contains information that is to be transmitted [12]. The study takes modulation into consideration so as to be able to analyse the behaviour of TV Broadcast signals.

Quadrature Amplitude Modulation (QAM) is the type of modulation which is widely used for radio communications because it offers advantages over other forms of data modulation such as Phase Shift Keying (PSK). A QAM signal has two carriers shifted in phase by 90 degrees which are modulated and the subsequent output contains of both amplitude and phase variations. Since both amplitude and phase variations are present it may also be considered as a mixture of amplitude and phase modulation [13]. Both amplitude and phase variations to represent binary data. The digital form of QAM can be referred to as "Quantised QAM" and its progressively used for radiocommunication systems ranging from DVB broadcasting to cellular technology including WiMAX and Wi-Fi 802.11 [14].

For 16QAM type, 4bits are represented by one complex symbol as shown below. For 64QAM, 6 bits are characterized by one complex symbol and so on. As the modulation order in QAM increases, it maps more number of bits per carrier but phase transition between the symbols decreases. This makes receiver more complex in order to recover the original information bits [9].

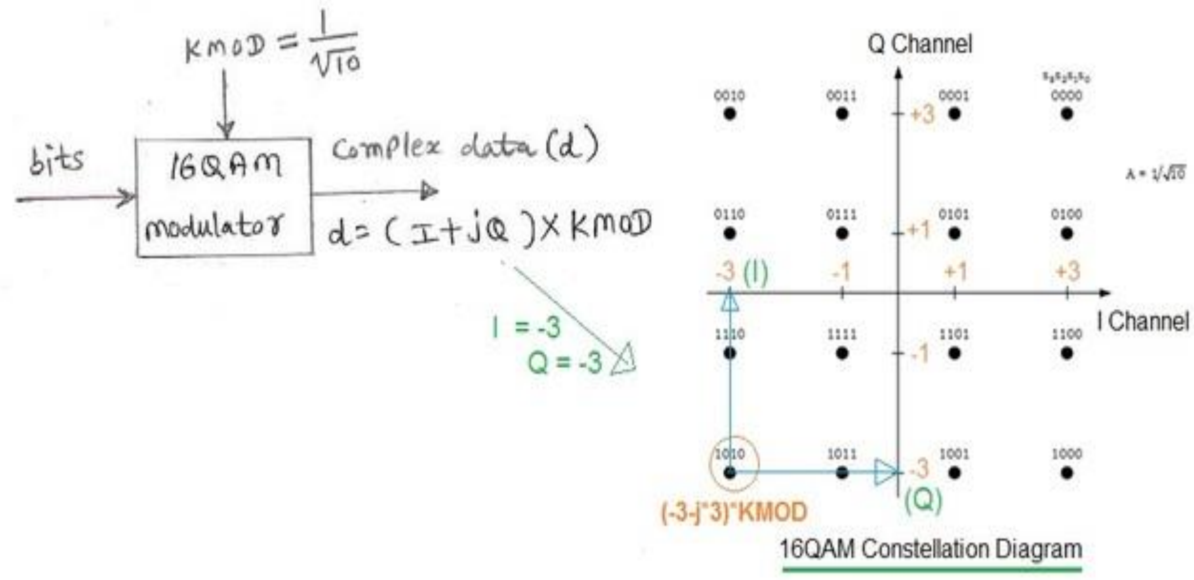

Fig 2.10 QAM Constellation diagram

QAM is able to sustain higher data rates than ordinary amplitude modulated schemes and phase modulated schemes. As with PSK, the number of points at which the signal can rest, i.e. the number of points on the constellation is indicated in the modulation format description, e.g. 16QAM uses a 16point constellation. When using QAM, the constellation points are normally arranged in a square grid with equal vertical and horizontal spacing and as a result the most common forms of QAM use a constellation with the number of points equal to a power of 2 i.e. 2, 4, 8, 16. Ultimately, by using higher order modulation formats, resulting in more points on the constellation, it is possible to transmit more bits per symbol. However, the points are closer together and they are more susceptible to noise and data errors.

2.9 Line of Sight Propagation Theory

A look at Line of Sight Propagation, is critical to the study since the TVWS system utilises this type of propagation. Line of Sight Propagation (LoS) is a type of propagation that transmits and receives data only where transmit and receive stations are in view of each other without any sort of an obstacle between them [12]. FM radio, microwave and satellite transmission are examples of line-of-sight communication.

Long-distance data communication is effective over wireless networks but geographical obstacles and the curvature of the earth bring limitations to line-of-sight transmission. However, these issues can normally be alleviated through preparation, calculations and the use of supplementary technologies [14].

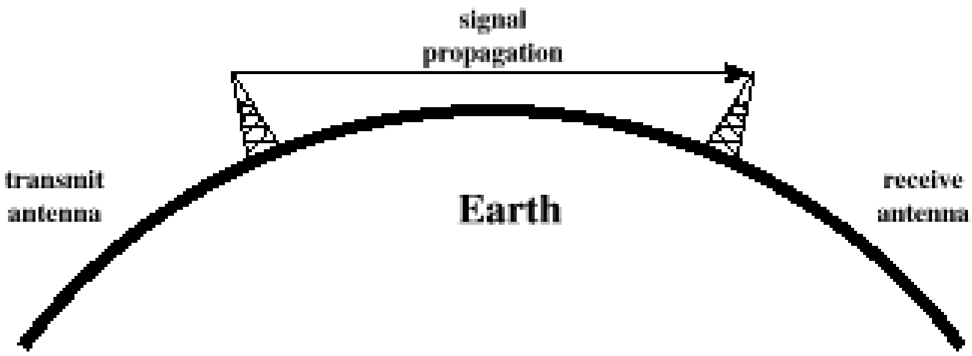

Fig 2.11 Line of Sight Propagation

Electromagnetic transmission in this propagation mode includes waves traveling in a straight line. The waves may be diffracted, refracted, reflected, or absorbed by atmosphere and obstructions and they usually cannot travel over the horizon or behind obstacles.

At low frequency (below approximately 3 MHz), radio signals travel as ground waves, which follow the Earth's curvature due to diffraction with the layers of the atmosphere. This enables AM radio signals in low-noise environments to be received well after the transmitting antenna has dropped below the horizon.

Additionally, frequencies between approximately 1 and 30 MHz can be reflected by the F1/F2 Layer, thus giving radio transmissions in this range a potentially global reach, again along multiple deflected straight lines [9].

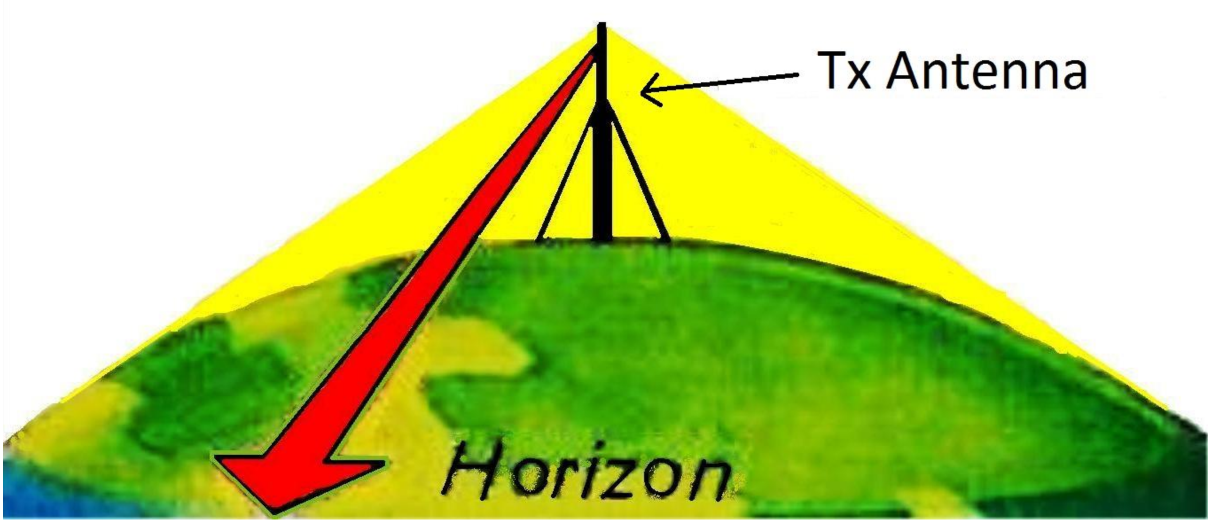

Fig 2.11 The Scope of Line of Sight Propagation

However, at frequencies above 30 MHz (VHF and higher) and in lower levels of the atmosphere, these effects are insignificant. Thus, any impediment between the transmitter and the receiver will block the signal. Consequently, the propagation characteristic at these frequencies is called "line-of-sight". The furthest possible point of propagation is denoted as the "radio horizon".

2.10 Frequency Planning Theory

In the radio spectrum, key frequency bands in UHF and VHF are being used even more intensively. The switchover from analogue to digital TV; the introduction of new facilities such as LTE in 800 MHz; and the growth of advanced new technologies like TVWS all place new demands on the spectrum. As an effect, there is increasing dependence on frequency planning and spectrum management information to ensure that spectrum is used as competently as possible whilst ensuring the protection of the services that use it.

The licensing and spectrum management authority, plays a major part in this planning and spectrum management process. Basically Frequency Planning is the procedure of assigning frequencies, transmitter locations and parameters of a wireless communications system to provide sufficient *coverage* and *capacity* for the services required. The plan typically has two objectives: coverage and capacity. Coverage relates to the geographical footprint within the system that has sufficient RF signal strength to provide for transmission. Capacity relates to the competence of the system to withstand a number of users. Capacity and coverage are interconnected. To improve coverage, capacity has to be sacrificed, while to improve capacity, coverage will have to be sacrificed.

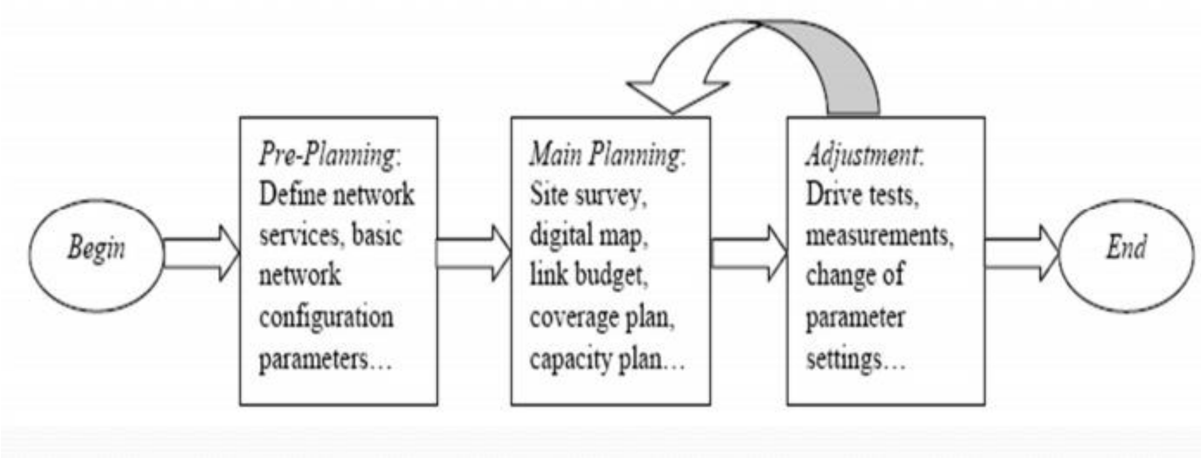

Fig 2.12 The Frequency Planning cycle work flow

Communication systems utilize Frequency Planning mainly to be able to effectively use the available spectrum too. The process involves pre-planning, main planning and adjustments to complete it. Frequency planning is critical to the study because the outcome of the study will help in the Main planning stage.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This segment of the study seeks to delve deeper into the metrics of the Radio Spectrum, TVWS, DVB-T and White Space Transmission. Study conclusions from [21], [22] have shown that present approximation-based methods for dynamic spectrum sharing, which involve arbitrarily placing secondary users to reuse spectrum allocated to primary users, cannot guarantee primary system protection.

The main purpose of this study is, therefore, to employ an effective spectrum sharing model capable of recovering radio spectrum in the UHF TV band, extenuating problems related with the estimate based techniques and using the model to quantify the available TVWS in Zimbabwe, thus in retrospect, suggesting alternative uses of the spectrum in the calculated Protected Regions. Although TVWS has previously been quantified in numerous countries, this work has employed a new perspective in quantifying the available TVWS in Zimbabwe. In all essence, the study should help identify the protection region, pollution region and the no talk region. Key aspects being minimal interference and coexistence.

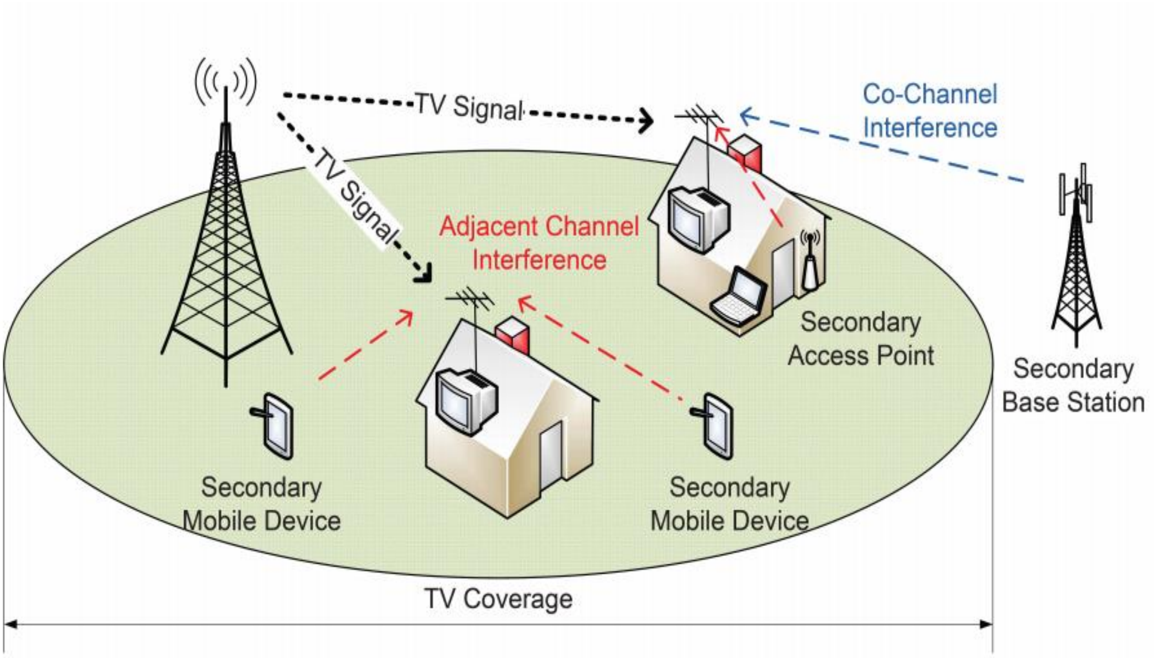

Fig 3.1 The setup of a typical TVWS system showing the priority of users

3.2 The Protection and Pollution Perspective

The study will adhere to the following methodology: Computational formulae will be used to calculate the protection region and separation distance for each of the towers to be covered in the study.

The '*protection*' perspective is derived from the ruling that stipulates that a White Space Device can only function in places where it won't produce destructive interference to TV receivers. We assume the notion of 'harmful interference' and the protection that is guaranteed to TV receivers. The notion being the idea of a 'fading margin' which protects the TV receiver from bad fading events. Once a secondary device starts transmission, it raises the noise floor and hence corrodes some of that fading margin. This protection margin decrees the number of TV receivers at the edge whose quality is potentially sacrificed to enable secondary operation. Along the same lines, the '*pollution*' perspective cogitates that the appeal of locations for secondary devices upsurges with increased distance from the primary transmitter due to the reduction in interference from the primary user. To quantify the white space obtainable under the '*pollution*' perspective, we can limit the amount of acceptable interference (above noise level) that the TVWS device can tolerate.

Both perspectives eliminate regions around a television tower and suggest that the actual necessary white space available is the joint region of the white space resulting from these two viewpoints. However, the study will be limited to the Protection Perspective, so as to deal with quantifying the White Space precisely.

Presently, there are no TV white space guidelines in Zimbabwe since the country is currently migrating to Digital Terrestrial TV. The regulations from FCC (United States) are borrowed for the estimation of TV white space. The parameters used by the study include the following for all the TV transmitters:

1) Position of the tower (latitude and longitude),
2) Transmission Power of the TV transmitter,
3) Frequency of operation,
4) Height of the antenna,
5) Terrain information of area surrounding the tower.

The above parameters of all the TV towers operating in the UHF band have been obtained from the national broadcaster, ZBC TV and regulatory organization, BAZ.

Using this TV transmitter information and the propagation model, we quantify the available TV white space in the UHF TV band by two methods. The first method utilizes the protection and pollution viewpoints while the second one utilizes technical specification made by the FCC.

3.3 Protection Parameters and Equations

In the protection viewpoint, when a secondary user operates, it must not cause any interference to the primary receivers in its vicinity. This is illustrated in **Fig 3.1** The protected area is defined using the following SINR equations.

Let:

- P_t be the Transmit Power of primary in **dBm**,
- $PL(r)$ be the path-loss in **dB** at a radial distance r from the transmitter,
- N_0 be the thermal noise in **dBm**
- Δ be the threshold SINR in **dBm**.

r_{nl} is the coverage area is the broadcast coverage area with no interference from other transmissions. Inside this zone, the nominal TV SNR is greater than the threshold SINR (Δ), hence, the Protection radius r_p is defined by the following SINR equation:

$$P_t - PL(r_p) - N_0 = \Delta.$$

Since it's the Protection perspective, a further margin (Ψ) is added to account for fading. Hence the altered equation for r_p is:

$$P_t - PL(r_p) - N_0 = \Delta + \Psi$$

$$P_t - PL(r_p) - N_0 - \Delta = \Psi$$

The no-talk radius r_n is the distance from the primary transmitter up to which no secondary device can transmit. The difference $(r_n - r_p)$ is computed such that if a secondary device transmits at a distance of $(r_n - r_p)$ from the UHF TV receiver positioned at r_p, the SINR at that receiver inside a radius r_n does not fall below Δ.

The separation distance $(r_n - r_p)$ is then calculated such that:

$$P_s - PL\ (r_n - r_p) = \Psi$$

where, P_s is the secondary transmitter power in dBm.

In this perspective, we consider that the protection radius in the adjacent channel is the same as in co-channel. The TV receiver can however endure more adjacent channel interference than co-channel interference. Therefore, a margin of **27dB more** than co-channel fading margin Ψ [24] is provisioned for situations with adjacent channel interference.

When a secondary user starts transmitting, the noise floor(N_0) is raised. Authorities must indicate the quantity of the protection margin, Ψ_t, that can be eroded to enable secondary operation. TV receivers close to r_{nl} can certainly lose service due to the additional interference. Nevertheless, equivalent to the selection of Ψ_t is the protected radius r_p where the original fading margin was equal to Ψ_t. In cognitive radio, this margin is reduced to zero but all TV receivers within r_p are still supposedly protected, meaning they can get reception by positioning their antennas suitably:

$$r_p = PL^{-1} (P_t - \Psi - N_0 - \Delta)$$

The protection radius r_p, the transmit power P_t, and antenna height of the secondary transmitter must then be used to determine the no-talk radius r_n. The TVWS/secondary transmitter can only transmit if it's outside the no-talk area of the primary transmitter.

The value of $(r_n - r_p)$ is critical in determining this distance beyond the protection radius where the secondary device can securely transmit.

In essence we need to determine the distance r_n such that a transmission from r_n results in a SINR of Δ at r_p.

Initially, the allowable interference level at r_p (I_{rp}) is determined as:

$$I_{r_p} = 10\ log_{10}\ (10^{\frac{Pt-PL(r_p)-\Delta}{10}} - 10^{\frac{N_0}{10}}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \{1\}$$

Then we determine $(r_n - r_p)$ as follows:

$$(r_n - r_p) = (L_o)^{-1} (P_s - I_{r_p}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\{2\}$$

Where:

P_s is transmit power (**in dBm**) of the TVWS device

I_{r_p} is the maximum allowed interference power (**in dBm**) from {1}

L_o is the optimistic path loss from the secondary device to the primary transmitter

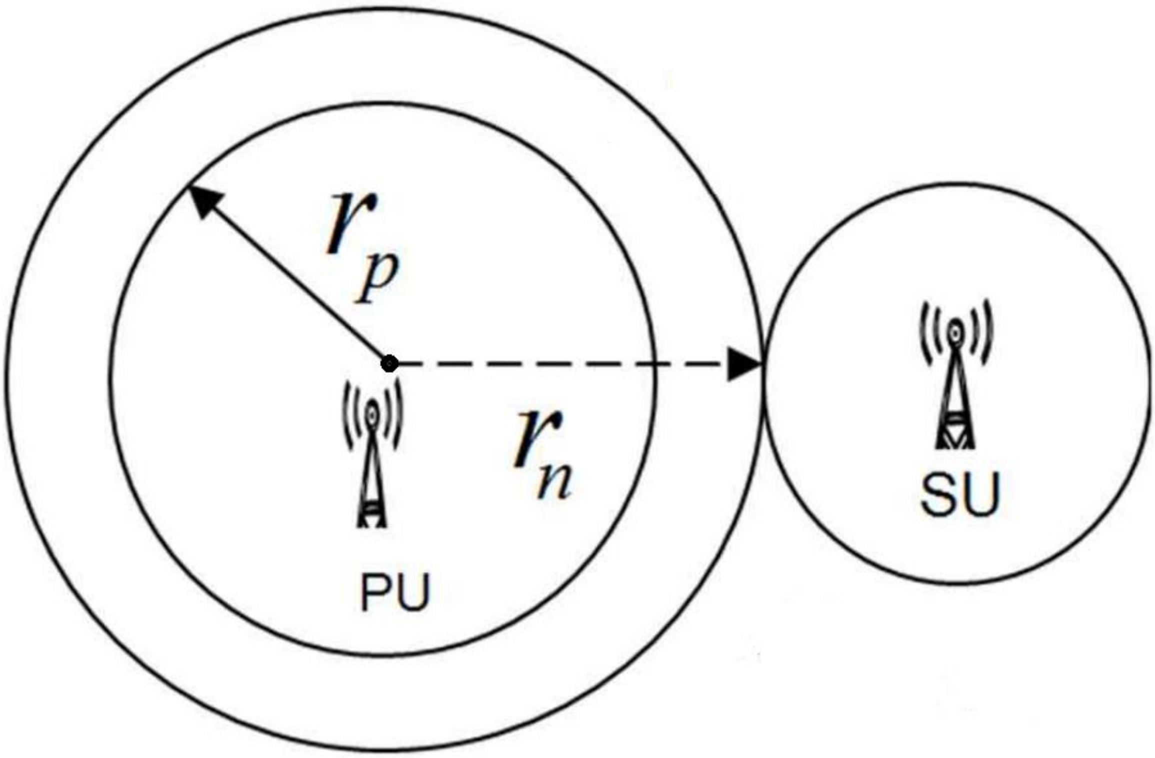

Fig 3.2 A summary of the radial contours and the distances to be calculated

3.4 Path Loss

During the process used to compute the values for r_p, nominal path loss PL, is assumed basing on the ITU's *F (50, 90)* path loss model. It basically states that the protection radius (r_p) is the distance where the SNR is Δ for 50% of the locations, 90% of the time.

3.5 Summary of Calculations

The study's calculations shall be based on the running example of the DTT transmitters in Kwekwe, Gokwe and Gweru to illustrate the Quantification. The DTT transmitters occupies channel channels from 474 to 490 MHz, and is placed at average height above sea level of 100m and a uniform transmit power of 1.1kW.

To conclude the *propagation characteristics* of this tower we need to calculate the effective height of the tower, HAAT (Height Above Average Terrain). To obtain this figure, ground elevation of random points around the tower at 10 evenly spaced radials from the transmitter site. The elevation points along each radial are averaged, then the radial averages are averaged to calculate the average height of the terrain. Subtracting this value from the height of the tower gives the HAAT of the tower.

Operational SINR of the DTT transmitters is also vital. Since [23] states that the desired Signal to Interference ratio (SIR) ratio at the (Grade B contour) is 23dB.

3.5.1 Protection Region

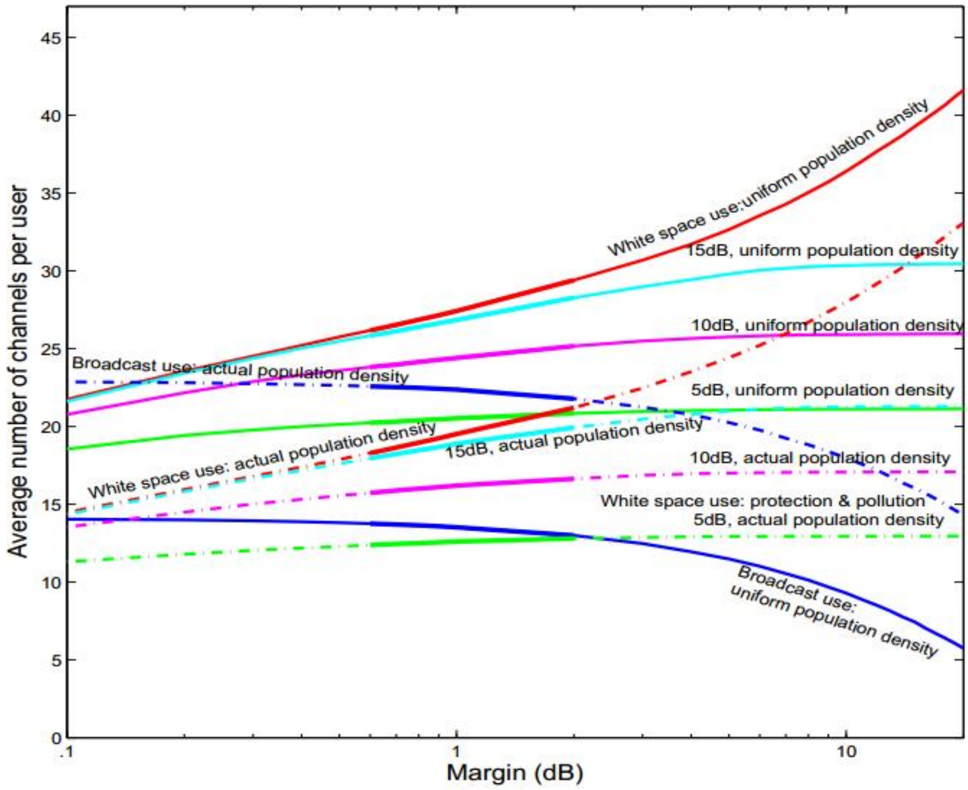

Fig 3.3 The median of Fading margins

Above, the FCC calculations considering several uses of the spectrum, increase the range of fading margin values which have a median of 1dB. This shall be used as the target fading margin (Ψ = 1**dB**).

Hence r_p is the distance at which the signal strength is greater than:

$$N_0 + \Delta + \Psi = \_\_\_\_\_ \ dBm$$

for 50% of the locations, 90% of the time.

For channels in 470-490 MHz, this transforms to an electric field measured in **dBu** (E_{r_p} (**dBu**)).

E_{r_p} (**dBu**) was used to calculate the r_p using the following procedure:

• The *Effective Radiated Power* is converted to *Effective Isotropic Radiated Power*

(*EIRP* (**dBm**) = *ERP* (**dBm**) + 2.15dB).

• The *Electric Field* at a distance of 1m from the transmitter is calculated as:

$$E_{1m}(\text{dBu}) = 104.8 + EIRP\ (\mathbf{dBm}),$$

• The essential *Path Loss* is calculated as:

$$PL\ (\mathbf{dB}) = E_{1m} - E_{rp}$$

• The ITU-R recommendations are used to determine the maximum distance (beyond 1m) at which the path loss is less than (or equal to) PL for 50% of the locations, 90% of the time.

3.5.2 No-Talk Region

To calculate r_n we first calculated the distance beyond the protected radius where the secondary can transmit $(r_n - r_p)$ i.e. we need to determine the distance r_n such that a transmission from r_n results in a signal level at r_p of I_{rp} (see Equation 1). After we converted I_{rp} to an electric field, we used the procedure outlined in (as in 3.5.1) to determine
the value of $r_n - r_p$ with the exception that we used the F (50, 10) propagation curves for predicting the distance. This was to ensure that transmissions from a secondary just
outside rn can cause harmful interference only 10% of the time.

3.6 Conclusion

Ultimately, the equations used in the study have looked at all feasible aspects of the spectrum and the communications link in order to come out with the two contours. This is so as to quantify the available white space per site.

Observation is made along the way, that the amount of white space is reliant on terrain and user density. The contour approach based on protected regions is suggested to conclude the allowable secondary transmit power and relative transmission distance, from the TVWS Base Stations. The suggested approach considers influence of the secondary interference, such as, fading, antenna directivity, random disposition of secondary users and the accumulative effect of interferences.

However, results shall show that, this approach will accurately predict much more accurate levels permissible transmit power than the existing deterministic frameworks, while providing a reliable DTT user protection. Moreover, this approach can be easily applied to the real-world scenarios. A practical application of a scenario where the model of the study can be used will be proposed in the next chapter.

CHAPTER FOUR

RESULTS, ANALYSIS & RECOMMENDATION

4.1 Introduction

Utilising the parameters and formulae to establish the Protection margin and acceptable interference and secondary transmit power levels is realized in this chapter. Theoretical results as well as Graphical results are displayed. Ultimately the recommendation for Rural broadband is offered and justified at the end of the Chapter.

The scope of the study is shown below, in the way of particular TV Tower parameters.

Bulawayo	498	100	2600	6*6*6*6
Chinhoyi	594	100	1100	4*4*4*4
Chiredzi	626	100	1100	4*4*4*4
Chivhu	570	100	1100	4*4*4*4
Gokwe	474	100	1300	6*6*6*6
Gutu	490	100	1100	4*4*4*4
Gwanda	626	100	1300	6*6*6*6
Gwendingwe	682	120	1100	4*4*4*4
Gweru	482	100	1300	6*6*6*6
Harare	618	100	2600	6*6*6*6
Hwange	474	100	1100	4*4*4*4
Insiza	610	100	1100	4*4*4*4
Insiza Junction	To be used as SFN for gap filling		1100	4*4*4*4
Kadoma	602	100	1100	4*4*4*4
Kamativi	626	120	1100	4*4*4*4
Kariba	618	55	1100	4*4*4*4
Karoi	626	120	1100	4*4*4*4
Kenmaur	618	120	1100	4*4*4*4
Kotwa	562	60	1100	4*4*4*4
Kwekwe	490	100	1100	4*4*4*4
Mapengola	498	100	1100	4*4*4*4

Fig 4.1 An extract containing main details of the UHF TV Towers used in the study

4.2 Mathematical Model

We study the TV towers situated at Guinea Fowl in Gweru, Nembudziya in Gokwe and Redcliff in Kwekwe. The regulator noted that the towers operates in the 474 – 490 MHz band at a height of 100m and power of 1.1kW (*60.41*dBm) and 1.3kW (*61.14*dBm).

Path loss calculations, in the 3 areas, which has been considered as a Rural area for most of the coverage areas, depicted varied levels of average path loss.

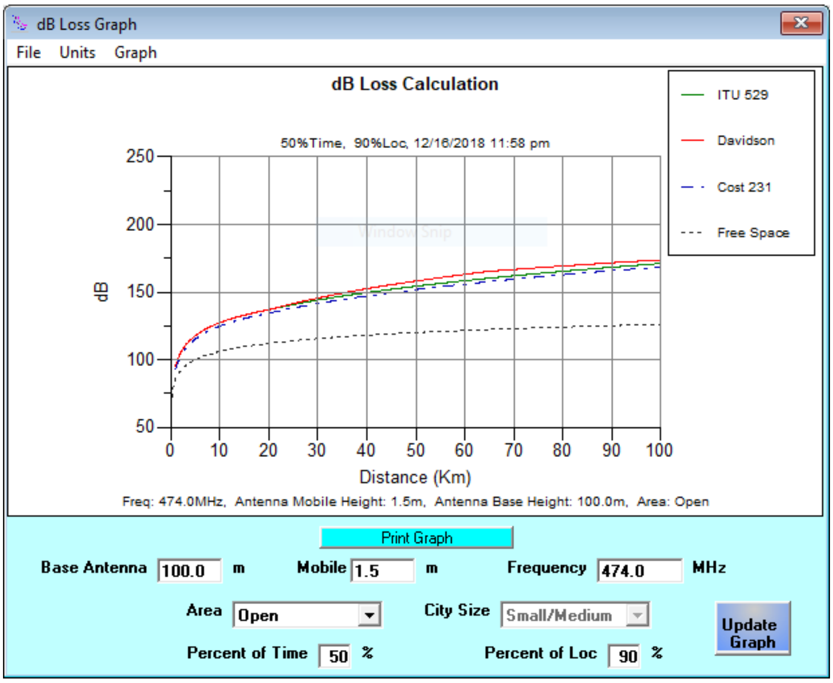

Fig 4.2 Path Loss graph for the Gokwe Tower

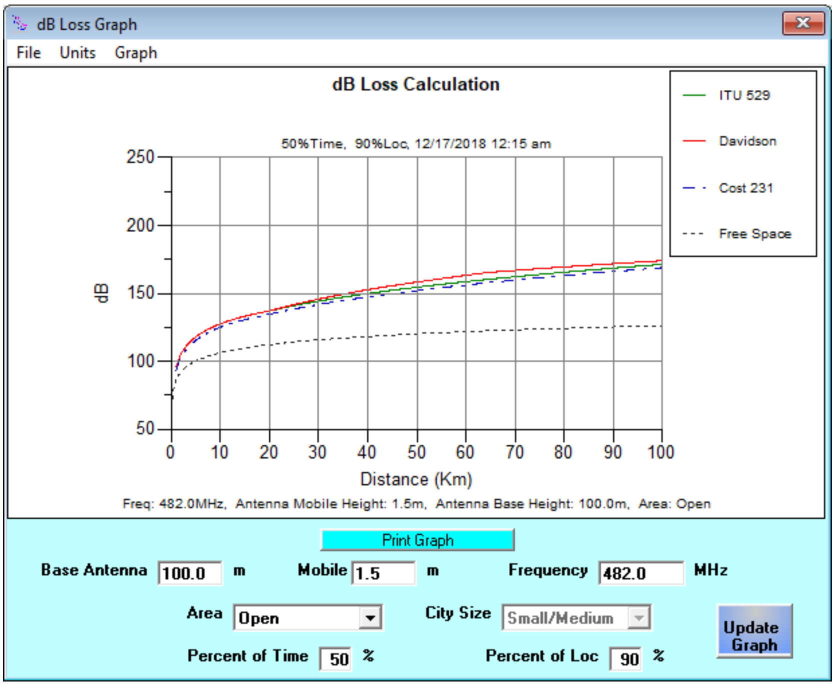

Fig 4.3 Path Loss graph for the Gweru Tower

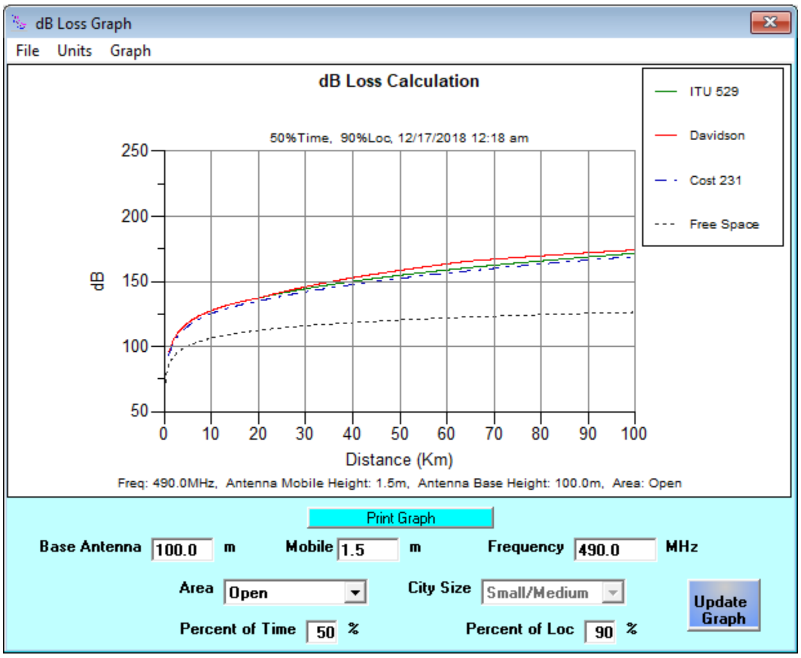

Fig 4.4 Path Loss graph for Kwekwe Tower

4.3 Parameters

The study used a few standard parameters:

Fading Margin(Ψ): 1 dB (30dBm)

Noise in 8MHz Channel (N_0): -105 dBm

Transmitter Gain: 11dBd

Threshold/Required SNR (Δ): 4.5dB

The following Parameters were used for each site:

SITE NAME	Gokwe	
CENTRE FREQUENCY	474.00	MHZ
TX HEIGHT	100	m
TX POWER	1300	W
ESTIMATED PATH LOSS	16.415	dB

Table 4.1 Site Parameters for Gokwe

SITE NAME	Gweru	
CENTRE FREQUENCY	482.00	MHZ
TX HEIGHT	100	m
TX POWER	1300	W
ESTIMATED PATH LOSS	17.435	dB

Table 4.2 Site Parameters for Gweru

SITE NAME	Kwekwe	
CENTRE FREQUENCY	490.00	MHZ
TX HEIGHT	100	m
TX POWER	1100	W
ESTIMATED PATH LOSS	16.454	dB

Table 4.3 Site Parameters for Kwekwe

4.4 Results

Using the protection perspective, with a fading margin of 1dB, the protection radius results are as follows:

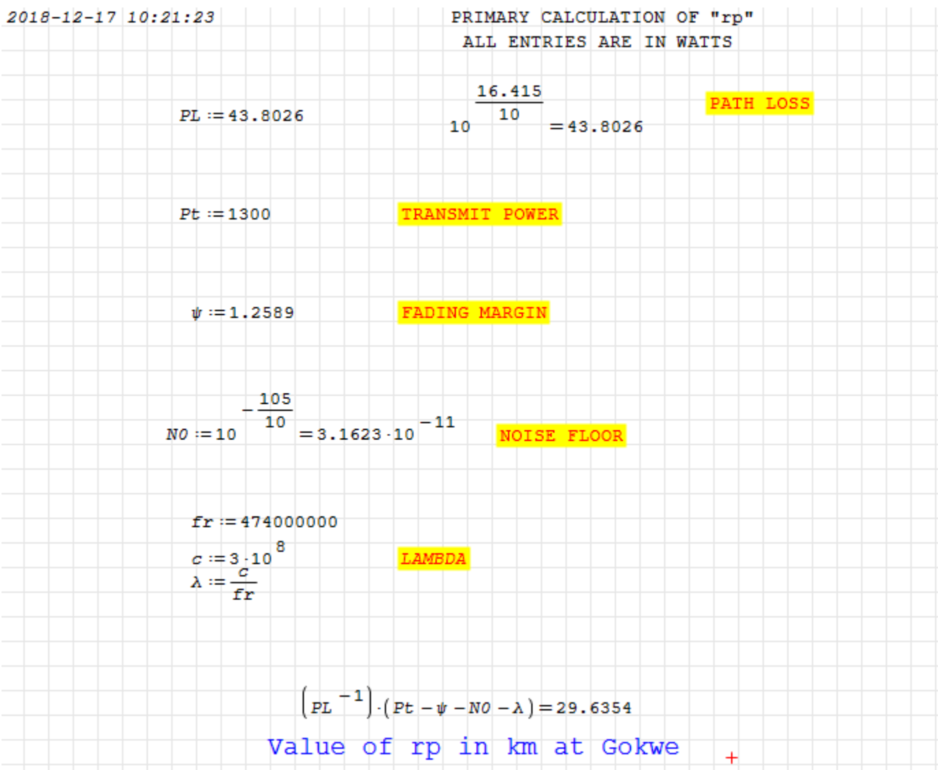

Fig 4.5 Calculated r_p distance in km, at Gokwe Tower

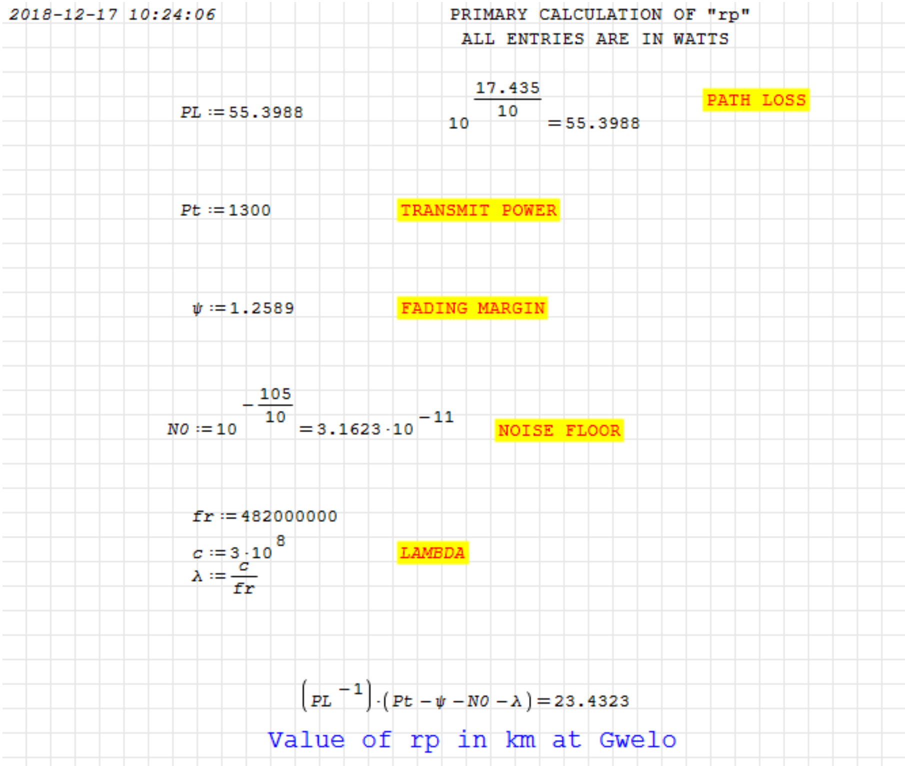

Fig 4.6 Calculated r_p distance in km, at Gweru Tower

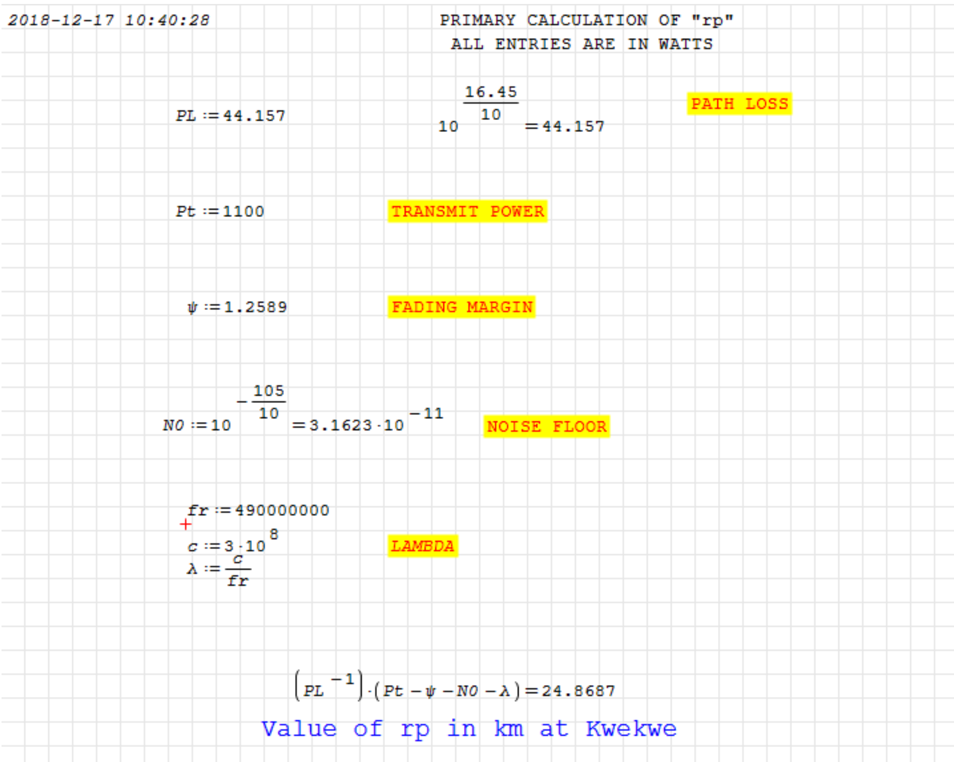

Fig 4.7 Calculated r_p distance in km, at Kwekwe Tower

Separation Distance Calculations Yielded the following results:

CALCULATIONS OF Irp at Gokwe Tower

ALL UNITS IN WATTS

$Pt := 1300$ TRANSMIT POWER

$PL := 10^{\frac{16.145}{10}} = 41.1623$ PATH LOSS

$\Delta := 10^{\frac{4.5}{10}} = 2.8184$ THRESHOLD SNR

$N0 := 10^{-\frac{105}{10}} = 3.1623 \cdot 10^{-11}$ NOISE FLOOR

$$10 \cdot \log_{10}\left(10^{\frac{Pt - PL - \Delta}{10}} - 10^{N0}\right) = 1256.0193$$

ALLOWABLE INTERFERENCE LEVEL = $10 \cdot \log10(1256.0193) = 30.99$

Fig 4.8 Allowable Interference at Gokwe

CALCULATIONS OF Irp at Gweru Tower

ALL UNITS IN WATTS

$Pt := 1300$ TRANSMIT POWER

$PL := 10^{\frac{17.435}{10}} = 55.3988$ PATH LOSS

$\Delta := 10^{\frac{4.5}{10}} = 2.8184$ THRESHOLD SNR

$N0 := 10^{-\frac{105}{10}} = 3.1623 \cdot 10^{-11}$ NOISE FLOOR

$$10 \cdot \log_{10}\left(10^{\frac{Pt - PL - \Delta}{10}} - 10^{N0}\right) = 1241.7829$$

ALLOWABLE INTERFERENCE LEVEL = $10 \cdot \log10(1241.7829) = 30.9405$

Fig 4.9 Allowable Interference at Gweru

CALCULATIONS OF Irp at Kwekwe Tower

ALL UNITS IN WATTS

$Pt := 1300$ TRANSMIT POWER

$PL := 10^{\frac{16.45}{10}} = 44.157$ PATH LOSS

$\Delta := 10^{\frac{4.5}{10}} = 2.8184$ THRESHOLD SNR

$N0 := 10^{-\frac{105}{10}} = 3.1623 \cdot 10^{-11}$ NOISE FLOOR

$10 \cdot \log_{10}\left(10^{\frac{Pt - PL - \Delta}{10}} - 10^{N0}\right) = 1253.0246$

ALLOWABLE INTERFERENCE LEVEL = $10 \cdot \log 10(1253.0246) = 30.9796$

Fig 4.10 Allowable Interference at Kwekwe

The Allowable Interference allows us to obtain the Separation Distance (r_n - r_p):

CALCULATIONS OF SEPARATION DISTANCE "rn-rp"

ALL UNITS IN dB FORM

GOKWE TOWER

$$(r_n - r_{p)} = (L_o)^{-1} \, (P_s - I_{r_p})$$

$Lo := 0.9 \cdot (16.415) = 14.7735$ Losses are 90% effective since we used the (F50,10) model

$Irp := 30.99$ Calculated in Previous Results

$Ps := 120$ Optimistic Path loss of Device in TVWS Determined by Interference Threshold

$Lo^{-1} \cdot (Ps - Irp) = 6.025$

SEPARATION DISTANCE IN KM

Fig 4.11 Calculated Separation Distance at Gokwe

CALCULATIONS OF SEPARATION DISTANCE "rn-rp"

ALL UNITS IN dB FORM

GWERU TOWER

$$(r_n - r_p) = (L_o)^{-1}\,(P_s - I_{r_p})$$

$Lo := 0.9 \cdot (17.435) = 15.6915$ Losses are 90% effective since we used the (F50,10) model

$Irp := 30.9405$ Calculated in Previous Results

$Ps := 120$ Optimistic Path loss of Device in TVWS Determined by Interference Threshold

$Lo^{-1} \cdot (Ps - Irp) = 5.6757$

SEPARATION DISTANCE IN KM

Fig 4.12 Calculated Separation Distance at Gweru

CALCULATIONS OF SEPARATION DISTANCE "rn-rp"

ALL UNITS IN dB FORM

KWEKWE TOWER

$$(r_n - r_p) = (L_o)^{-1}\,(P_s - I_{r_p})$$

$Lo := 0.9 \cdot (16.454) = 14.8086$ Losses are 90% effective since we used the (F50,10) model

$Irp := 30.9796$ Calculated in Previous Results

$Ps := 120$ Optimistic Path loss of Device in TVWS Determined by Interference Threshold

$Lo^{-1} \cdot (Ps - Irp) = 6.0114$

SEPARATION DISTANCE IN KM

Fig 4.13 Calculated Separation Distance at Kwekwe

From the above calculated results, it is now possible to draw contour maps around the points which houses the Towers' Coverage Area.

Below is the tabular form of the actual values of r_n

Location	Actual Effective Radius (km)	Centre Frequency (MHz)	Protected Radius (km)	Separation Distance (km)	Accumulated No-Talk Distance (km)
Gokwe	70	474	29.63	6.02	35.65
Gweru	70	482	23.43	5.67	29.10
Kwekwe	50	490	24.86	6.01	30.87

Table 4.4 Calculated Values of r_n

Equating the Effective Radius to the Ratio of the Δ's, we get the ratio of the Anticipated Interference:

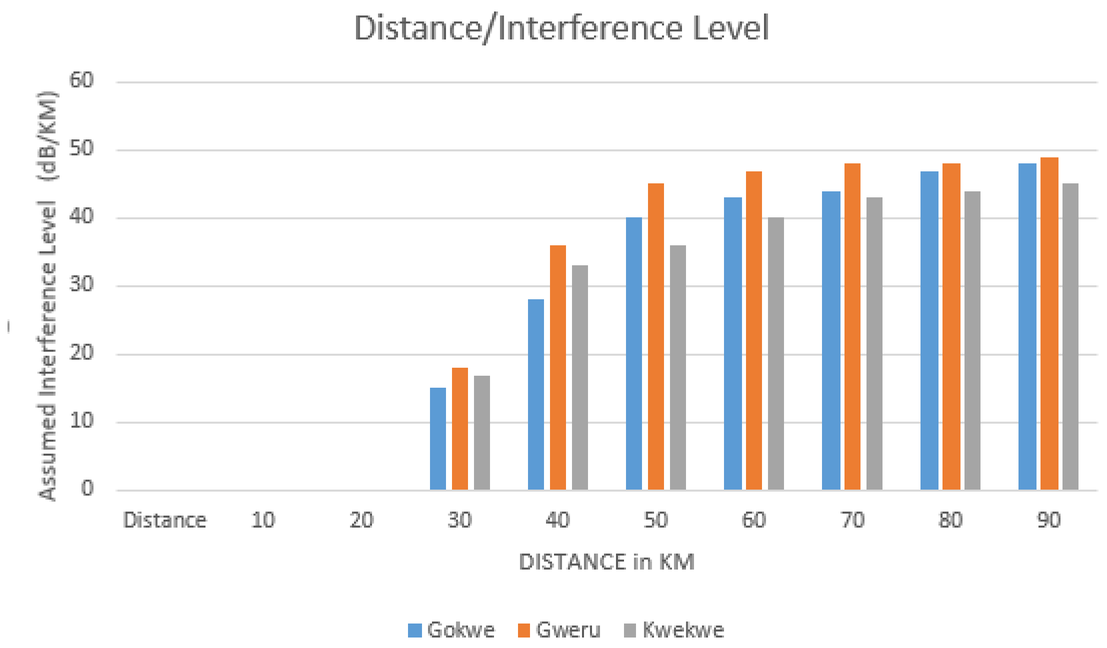

Fig 4.14 Distance per Interference

4.5 Contours

Basing on the data from calculations, the following contours were drawn up. The Maps show the calculated regions for each site. Satellite Imagery is used for accuracy purposes.

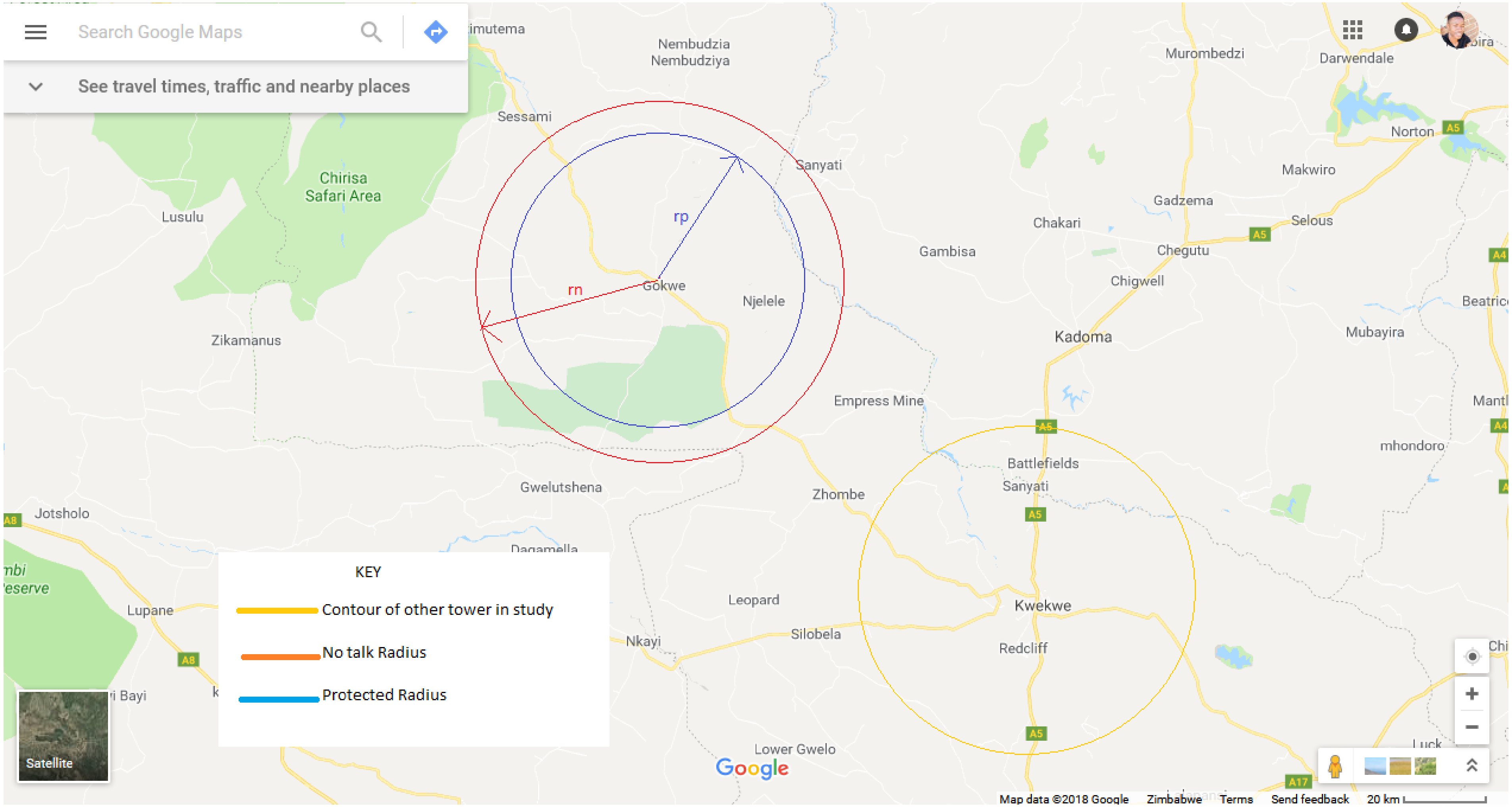

Fig 4.15 Contour map, showing the calculated regions according to the Gokwe Tower, also showing how near it is to the Kwekwe Tower's regions

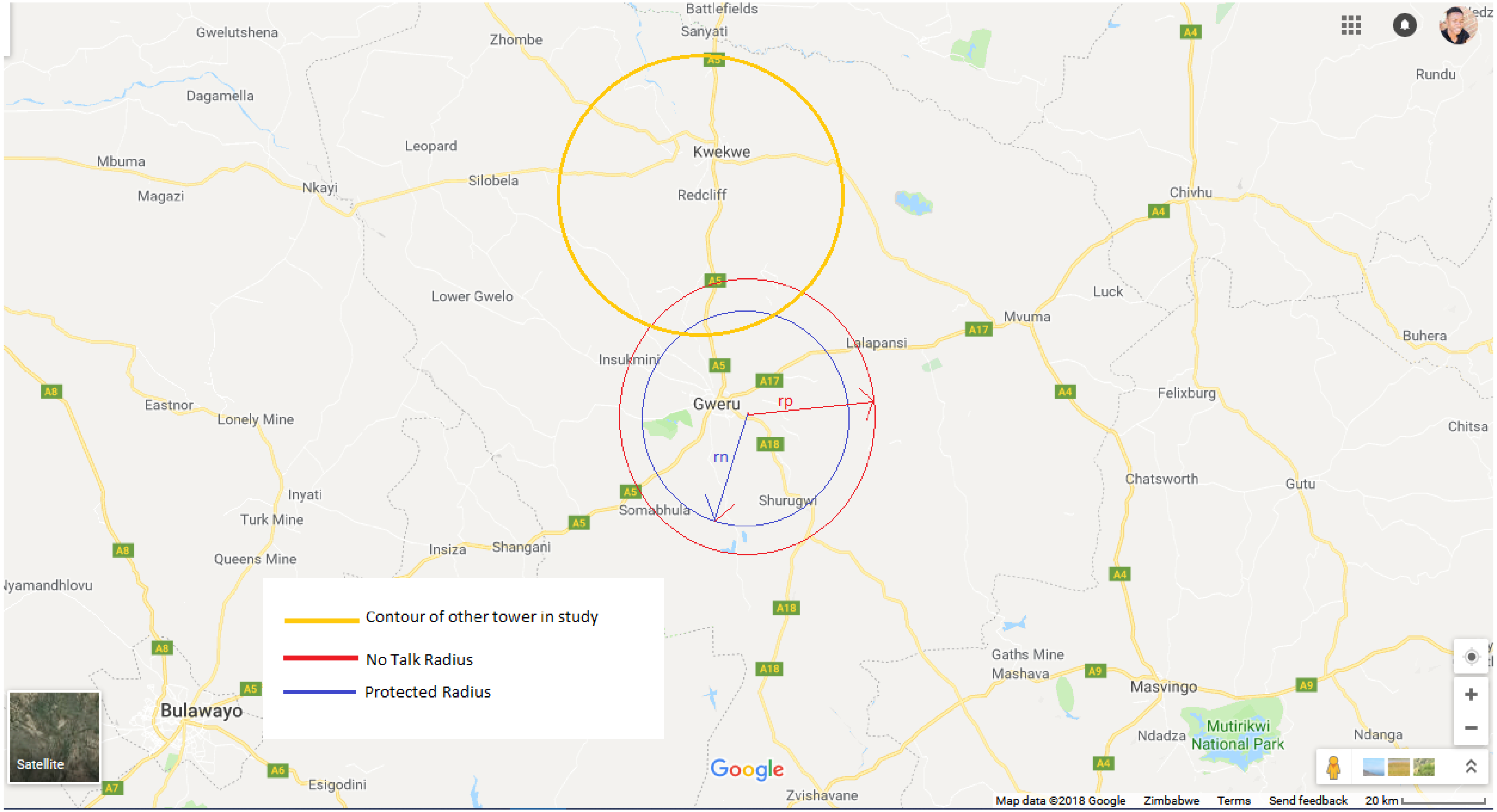

Fig 4.16 Contour map, showing the calculated regions according to the Gweru Tower, also showing how near it is to the Kwekwe tower's regions

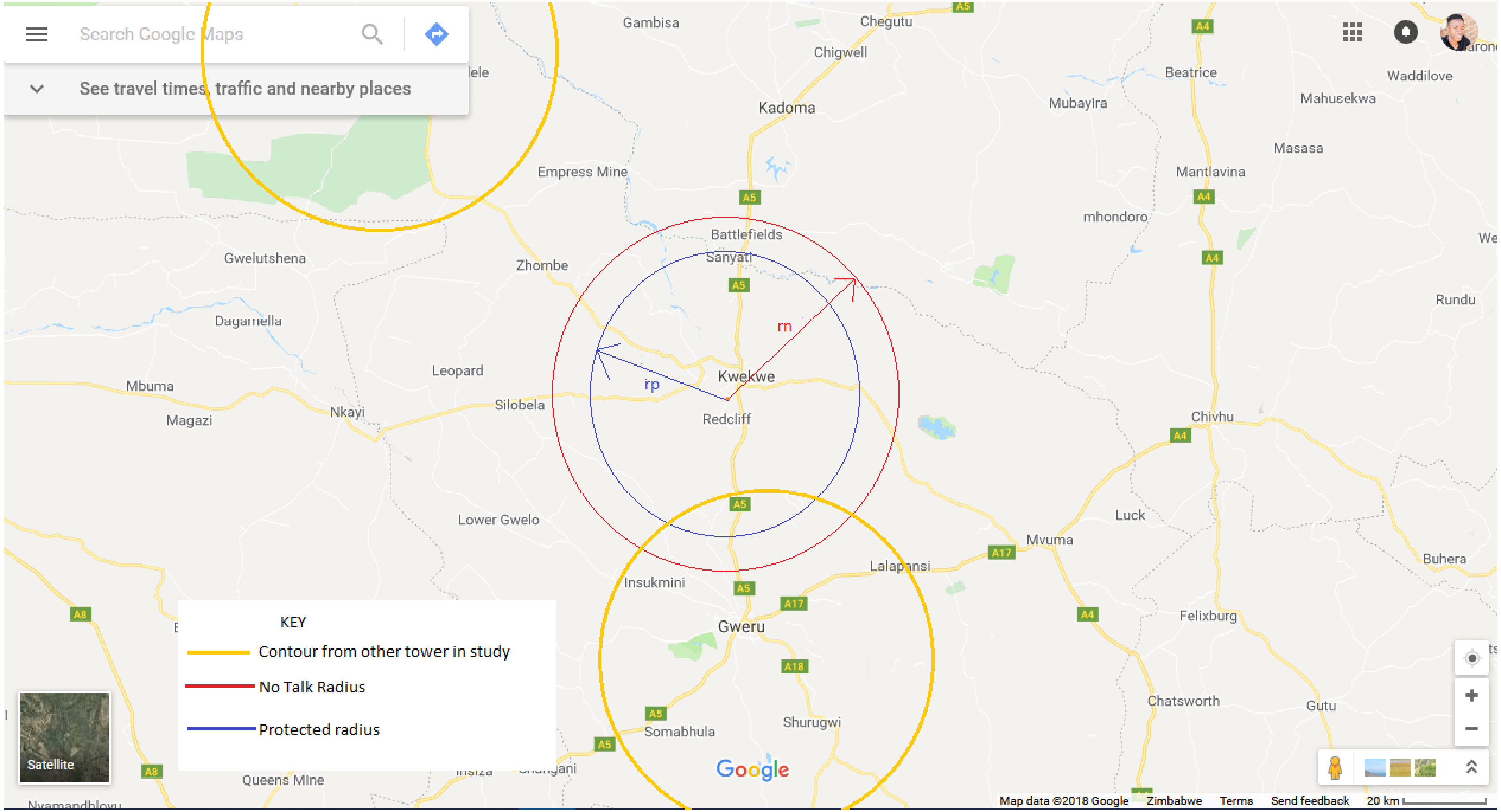

Fig 4.17 Contour map, showing the calculated regions according to the Kwekwe Tower, also showing how near it is to the other two tower's regions

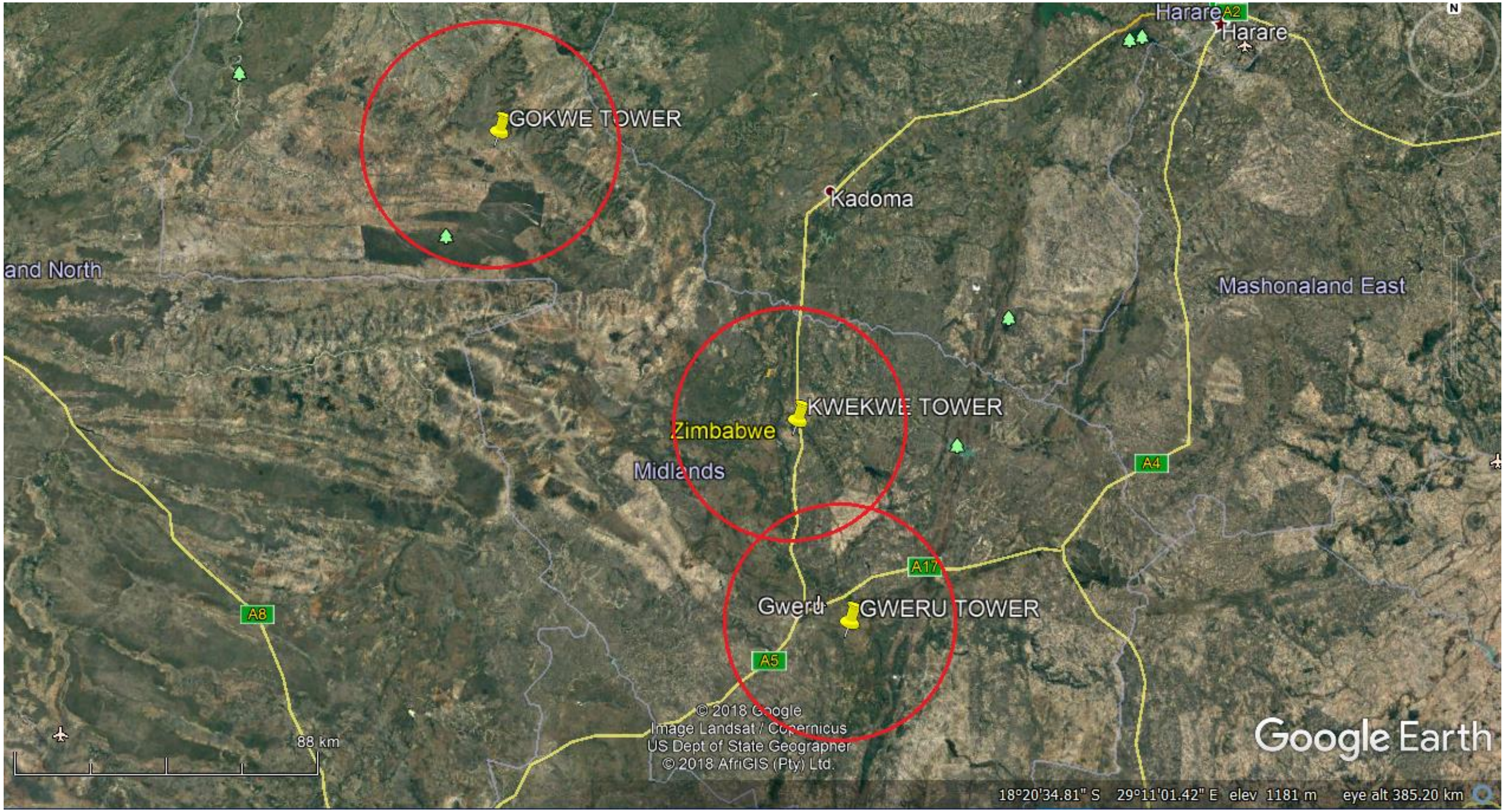

Fig 4.18 Satellite Map, showing the three calculated no talk

Fig 4.19 An aerial view of the Gweru Tower at Guinea Fowl

4.6 Recommendation

Following analysis of the white space available in the studied Midlands area, it would be feasible to deploy a TVWS based communication network for broadband expansion in the rural areas of the province. The writer envisions two deployment strategies. One being a master-slave relationship between the WSDs and also a point-to-multipoint topology for the TVWS network.

In the first scenario, the slave WSD will emulate Wi-Fi, WiMAX Hotspot or traditional TVWS standards such as *802.11af*.

The second scenario depicts the TV band being utilised to provide middle mile connectivity to Base stations and repeaters to reach far rural areas which are then connected via Wi-Fi in the last mile.

The rural areas can benefit to a greatly by the assignment of TVWS because of the absolute nature of the TV band waves having propagation characteristics to reach tens of kilometres. These networks are fast in deployment with negligible number of repeaters.

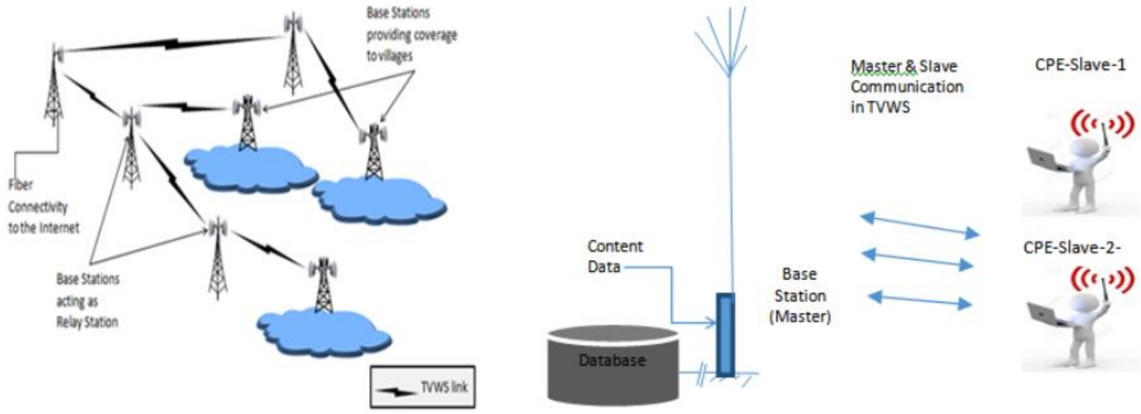

Fig 4.20 The two deployment scenarios of TVWS Broadband technology

4.7 Chapter Conclusion

This chapter successfully analysed the computational model used in the study to get results of the safe distances for TVWS transmission. With the unparalleled surge in mobile data traffic, the necessity for greater bandwidth to accommodate this increase. TVWS affords the vision to improve present licensed spectrum by manipulating unused resources, because of their inherent properties, as incumbent TV channels do not change in a particular location.

The contours shown, are proof that there exist large areas of this unused spectrum in the rural areas of the study area.

Further recommendations were also made, to ultimately achieve the goal of the research question.

CHAPTER 5

CONCLUSION

5.0 Conclusion

This chapter provides a summary and conclusion of the dissertation. The inferences of the project findings are discussed. It includes the implications for the practice, key findings as well as future references. It is key to initially note that the study was carried out with minimal challenges, due to its direct nature.

In the study, quantitative analysis of the available TV white space in the 470-890MHz UHF band was performed. Observation was made, that, that unlike in developed countries, a large percentage of TV band spectrum is unutilized in Zimbabwe.

Application of the TVWS network and operation, monitoring and performance are also key to the viability of the technology. The utilization of TVWS in Malawi has validated how vacant TV channels can be leveraged to deliver broadband connectivity to rural areas with emphasis on minimising interference on the primary signal.

5.1 Key Findings

Below is the summary of some key discoveries that were made during the course of the study. The field of TVWS is relatively untouched in Zimbabwe, and it would be beneficial for further studies to be carried out pertaining to this line of study.

5.1.1 Capacity

The results show that in at least 36% of areas around the regions, almost 100% of the TV band spectrum is free. The average available TV white space was calculated using the protection viewpoint, in conjunction with some FCC rules.

5.1.2 Protection for TV receivers

During the calculations, it was discovered that, in order to achieve required protection criteria from determination, “noise limited sensitivity” in the broadcasting UHF band is required. Calculations show that -58 dBm, is low enough sensitivity to achieve the Protection region successfully.

5.1.3. Protection of Broadcast Services

Unlicensed devices cannot cause interference to authorized, protected services and must admit and acknowledge any interference received.

The writer also suggests that that applicants who seek to operate a TVWS device or service, experience a public trial-run of 30 or more days to permit broadcasters and members of the public to sample test its ability to defend against interference. These suggested rules are likely to be further enhanced for improved competences in further revisions to the rules.

5.2 Closing Remarks

The idea of TVWS in Zimbabwe remains a gold mine, that needs to be tapped to unlock new methods and strategies to counter the challenges brought about by rising demand for spectrum and the dreaded Digital Divide.

REFERENCES

[1]. M. Islam et al., "*Spectrum survey in Singapore: occupancy measurements and analysis*", May 2008, pp. 1-8.

[2]. M. Wellens, J. Wu, and P. Mahonen, "*Evaluation of spectrum occupancy in indoor and outdoor scenario in the context of cognitive radio*", Aug 2007, pp. 420-427.

[3]. M. Mishra and A Sahai, "*How much white space is there?*" EECS Technical Report, Tech. Rep. EECS-2009-3, Jan 2009.

Available online at http://www.eecs.berkley.edu/Pubs/TechRpts/2009/EECS-2009-3.html

[4]. J. van de Beek, J. Riihijarvi, A. Achtzehn, and P. Mahonen, "*TV White Space in Europe*", IEEE Trans. Mobile Computing, Vol. 11, No. 2, 2012, pp. 178-188.

[5]. T. Dudda, T. Irnich, and J. Karlsson, "*How much TV white space is there in Germany?*", in 17th ITG-Fachtagung: Technologies and Andwendungen,Osnabruck, May 2012.

[6]. "*Consolidated spectrum audit and monitoring report: 450-470 MHz*", Electronic, Independent Communications Authority of South Africa (ICASA), May 2010.

Available online: http://www.icasa.org.za

[7]. "*Consolidated spectrum audit and monitoring report: 790-862 MHz*", Electronic, Independent Communications Authority of South Africa (ICASA), May 2010.

Available online: http://www.icasa.org.za

[8]. M. Masonta, D. Johnson, and M. Mzyece, "*The white space opportunity in Southern Africa: Measurements with Meraka cognitive radio platform*", in Lecture Notes of the Institute for Comp. Sci., Social Informatics and Telecomm. Eng., Springer Berlin Heidelberg, Vol. 92, 2012, pp. 64-73.

[9]. Digital Dividend: Insights for Spectrum Decisions: http://www.itu.int/ITU-D/tech/digital_broadcasting/Reports/DigitalDividend.pdf

[10]. "*Recommendations for Implementing the Use of White Spaces: Conclusions from the Cambridge TV White Spaces Trial*", available at: http://research.microsoft.com/en-us/projects/spectrum/cambridge-tv-white-spaces-trial-recomms.pdf

[11]. David, S., Zennaro, M., & Muchanga, A. (2015). "*The Internet @ rural: why not TV-White spaces in Mozambique?*" In 12th Prato CIRN Conference 9-11 Nov 2015, Prato, Italy.

[12]. A. A. Ghirardi, "*Radio Physics Course, 2nd ed*". New York:

Rinehart Books, 1932, pp. 29.

[13]. J. A. Fleming, "*The Principles of Electric Wave Telegraphy and Telephony*", London: Longmans, Green & Co., 1919, p. 33

[14]. Seybold, J. S. (2005). "*Introduction to RF Propagation*". Wiley and Sons. pp. 55–58

[15]. SADC Regional Frequency Allocation Plan

[16]. "*Zimbabwe National Frequency Allocation Plan*". Government of Zimbabwe. 2013

[17]. *"Huawei-BAZ DTT and FM Solution"*. Government of Zimbabwe. 2015

[18]. M.Zennaro, E.Pietrosemoli, JSP Mlatho, M.Thodi, C.Mikeka, "*An Assessment Study on White Spaces in Malawi Using Affordable Tools*", in proceedings of the IEEE Global Humanitarian Technology Conference 2012.

[19]. T. Ramoroka, "*Wireless internet connection for teaching and learning in rural schools of South Africa: the University of Limpopo TV white space trial project,*" Mediterranean Journal of Social Sciences, Vol. 5, No. 15, 2014.

[20]. M. Masonta, R. Makgotlho and F. Mekuria, "*Setting Scene for TV White Spaces and Dynamic Spectrum Access in South Africa.,*" IST-Africa 2012 Conference Proceedings, Dar es Salaam, Tanzania.

[21] R. Dahama, K.W. Sowerby and G.B. Rowe, "*Protection regions for dynamic spectrum Sharing*", ELECTRONICS LETTERS, Vol. 46 No. 20, Sept 2010.

[22] R. Dahama, K. W. Sowerby, and G. B. Rowe, "*Approximations for distributions of aggregate interference in spectrum sharing systems*," in Proc. IEEE Asia Pacific Conf. Communications, Auckland, New Zealand, pp. 95–100, 2010.

[23] *"In the Matter of Unlicensed Operation in the TV Broadcast Bands: Second Report and Order and Memorandum Opinion and Order,"* Federal Communications Commission, Tech. Rep. 08-260, Nov. 2008. [Online].
Available: http://hraunfoss.fcc.gov/edocspublic/attachmatch/FCC-08-260A1.pdf

[24] US Federal Communication Commission, "*Second Report and Order and Memorandum Opinion and Order*," Tech. Rep. 08-260, Nov. 2008.

[25] J. M. Chapin and W. H. Lehr. *Mobile broadband growth, spectrum scarcity, and sustainable competition*. In 39th Research Conference on Communication, Information and Internet Policy, Arlington, VA, USA, September 14–17 2011.

[26] A. A. Lysko, M.T. Masonta, and D. L. Johnson. "*Measuring the Television White Space Opportunity in Southern Africa Using Field Measurements*", pages 75–116. Springer, White Space Communications, D. L. Johnson & A. K. Mishra (Eds), 2015.

[27] A. A. Lysko, M. T. Masonta, and L. Mfupe. *Field measurements done on operational TVWS trial network in Tygerberg. Cape Town TVWS Tria*l - Technical Report, Available from: http://www.tenet.ac.za/tvws, 2013. [Accessed: 2018-08-19].

[28] Backens, J., Mweemba, G., & Van Stam, G. (2010). *A rural implementation of a 52 node mixed wireless mesh network in Macha, Zambia*. In A. Villafiorita, R. Saint-Paul, & A. Zorer (Eds.), E-infrastructures and e-services on developing countries, first international ICST conference, AFRICOM 2009, Maputo, Mozambique, December 3-4, 2009. Proceedings (Vol. 38, pp. 32–39). Berlin, Heidelberg: Springer.

[29] https://transition.fcc.gov/Daily_Releases/Daily_Business/2018/db0511/FCC-18-59A1.pdf Date Accessed: 2 August 2018

[30] http://www.internetlivestats.com/internet-users/zimbabwe/
Date Accessed: 5 August 2018

[31] https://www.theindependent.co.zw/2006/09/29/understanding-the-digital-divide/
Date Accessed: 5 August 2018