

**Coverage prediction and validation of digital terrestrial
television implementation in Zambia**

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degree of Master of Engineering in Telecommunication Systems

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DECLARATION OF ORIGINALITY

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Approval

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ABSTRACT

Digital Terrestrial Television (DTT) originates from the Regional Radio Communication Conference of 2006 (RRC06) and the subsequent Geneva 2006 agreement (GE06) of International Telecommunication Union (ITU) recommendations which made a resolution that member states signatory to the agreement must migrate from analogue to digital television broadcasting services. This was due to the frequency spectrum scarcity in order to accommodate mobile telecommunication services because the terrestrial TV frequency spectrum would no longer be exclusively used for terrestrial broadcasting. The resolution objective resulted into planning for Terrestrial-Digital Audio broadcasting (T-DAB) in the VHF range (174-230 MHz) and Digital Video Broadcasting (DVB-T) in the UHF range (470-862 MHz) of the television frequency spectrum.

Digital television system is latest initiative to impact Zambian television broadcasting systems since black and white conversion to color television transmission in the 1980's. DTT is modern and utilises advanced technology, which employs digital modulation techniques for the broadcasting of television services rather than analogue amplitude modulation system. This study highlights various technical factors that are critical to the success of DTT implementation in Zambia. The focus of this research is made to evaluate in details the DTT implementation plan, validate optimal application of Single Frequency Network (SFN) and Multiple Frequency Network (MFN) in order to attain full DTT coverage in Zambia. Furthermore, the footprint of DTT coverage, field signal strength levels, modulation and bit error rates of selected coverage areas were determined.

Simulations were made with accurate and update input data (antenna height, location, gain, transmit power, DVB-T2 parameters, etc) for the TV transmitting stations as provided by Zambian Government through the Ministry of Information and Broadcasting Services.

Finally, the calculated-simulated results were validated with signal field strength measurements using portable TV test receiver, indoor, a high precision calibrated and ordinary YAGI antennas. The simulated results ranged between 81.0 to 53.0dB μ V/M and signal field strength measured values ranged from 70.2 to 41.2 dB μ V/M, respectively. From both results, it was observed that MFN provided large signal coverage areas in relatively large flat lands and SFN in complex geographical terrains like Kafue and Chingola. Gapfiller transmitters (low power transmitters)

were recommended and to be installed in areas where MFN and SFN networks did not provide threshold signal field strength for set top boxes (STBs) to lock to DTT signal like Mazabuka and Chibombo. Vulnerable areas where digital terrestrial transmission would be a challenge to provide minimum signal strength for STBs to lock, the alternative recommended solution would be to obtain direct-to-home (DTH) satellite feed.

Dedication

I dedicate this thesis to my Heavenly Father and His Only Beloved Son, for keeping me in good-health throughout the rigors and trials of the research study, and for somehow keeping my mind sound during the long hours, days and nights, spent on searching, consultations and discussions. All sorts of scholarly materials, and the writing & rewriting & re-rewriting drafts, until the final version miraculously met the University of Zambia stringent dissertation acceptance standards. Forever Be Praised.

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Table of Content

Declaration of originality.....	i
Approval.....	ii
Abstract	iii
Acknowledgements.....	iii
Dedication.....	v
Table of Contents.....	vii
List of Abbreviations.....	xi
List of Figures	xiii
List of Tables	xv

CHAPTER ONE

1.0 Digital Terrestrial Transmission Background in Zambia.....	1
1.1 Adoption of DVB T2 and MPEG 4 compression for SADC members.....	2
1.2 Botswana adopts ISBT standards.....	3
1.3 Zambia DVB-T2 standards.....	4
1.4 Implementation challenges.....	5
1.5 Statement of the problem.....	6
1.6 Research questions.....	7
1.7 Objective of the project.....	7
1.8 Specific objectives of the dissertation.....	7
1.9 Research methodology.....	8
1.10 Relevance	8
1.11 Scope of study.....	8
1.12 Research contribution to the body of knowledge.....	9
1.13 Dissertation Organization.....	9
1.14 Summary.....	10

CHAPTER TWO

Literature Review.....	11
2.0 Introduction.....	11

2.1	Adoption and standard.....	12
2.2	DVB-T2 Standard.....	14
2.2.1	Technical Features of DVB-T2 architecture.....	14
2.2.2	Generation, Coding and Modulation of Layer 1 Signalling.....	15
2.2.3	Physical layer pipes.....	16
2.2.4	Coded Orthogonal Frequency Division Multiplexing Generation.....	18
2.2.5	Choice of Parameter for DVB-T2	20
2.2.5.1	Choice of Pilot Pattern.....	20
2.2.5.2	Choice of Rotated Constellations.....	22
2.2.5.3	Rotational angle in DVB-T2.....	24
2.2.5.4	Carrier-to-Noise Ratio C/N.....	25
2.3	Multiple frequency networks.....	26
2.4	Single frequency networks.....	27
2.5	Mixed MFN-SFN.....	33
2.6	Guard interval.....	33
2.7	Choice of Fast Fourier Transform for Single frequency networks.....	38
2.8	Model for the terrestrial receiver	39
2.9	Gapfillers (Fill-in) transmitters.....	39
2.10	Set Top Boxes.....	41
2.11	DTT implementation in Zambia.....	42
2.11.1	Digital television in Zambia.....	44
2.11.2	Implementation of DTT policy.....	44
2.11.3	Market structure and Licensing Framework.....	45
2.11.3.1	Content service provision.....	45
2.11.3.2	Private non-commercial content service provider.....	46
2.11.4	Signal distribution.....	46
2.11.4.1	Public signal distributor.....	46
2.11.4.2	Private signal distributor.....	47
2.12	Regulator and regulations.....	47
2.13	Zambia Bureau of standards STB specifications.....	47
2.14	Phase 1 DTT Implementation plan.....	48

2.15	Introduction of DTT coverage system.....	49
2.16	Signal distribution network.....	49
2.16.1	Video and audio encoding.....	50
2.16.2	DTT national headend.....	50
2.16.3	Remote monitoring system.....	51
2.16.4	Content integration platform.....	51
2.16.5	Programme composition.....	52
2.16.6	Electronic Programme guide.....	52
2.16.7	Summary.....	52

CHAPTER THREE

Methodology

3.0	Introduction.....	53
3.1	WRAP VERSION 4.8.1 management software.....	54
3.2	Signal Field measurement method.....	55
3.3	Summary.....	56

CHAPTER FOUR

Data Collection and analysis.....	58	
4.0	Introduction.....	57
4.1	Scenario 1: Antenna Radiating patterns.....	57
4.2	Multiple Frequency Network simulation.....	59
4.2.1	Scenario 2: Lusaka DTT MFN transmitter(682MHz).....	59
4.2.2	Scenario 3: Kapiri Mposhi MFN transmitter (610MHz).....	62
4.2.3	Scenario 4: Pemba DTT MFN transmitter(562MHz).....	64
4.2.4	Scenario 5: Senkobo DTT MFN transmitter(554MHz).....	65
4.2.5	Scenario 6: Gapfiller transmitter.....	65
4.2.6	Scenario 7: Technical Challenges.....	67
4.3	Single Frequency Network simulations.....	68
4.3.1	Scenario 7: Lusaka-Chilanga-Kafue.....	69
4.3.2	Scenario 7: Ndola-Kitwe-Chingola.....	71
4.4	Overall footprint for Phase 1 DTT implementation.....	74
4.5	Signal Field Strength Measurement.....	75

4.5.1 Outdoor (Yagi) antenna advantages.....	77
4.5.1.1 Measured values of the received signal.....	77
4.6 Limitation of the findings.....	81
4.7 Summary.....	81
CHAPTER 5	
Conclusions and recommendations.....	82
5.0 Introduction.....	82
5.1 Adoption of Digital Television in Zambia.....	84
5.2 Optimal application of Single and Multiple Frequency Networks.....	84
5.3 Signal field strength.....	85
5.4 Signal footprint in Zambia.....	86
5.5 Gapfiller recommendation.....	86
5.6 Future works.....	89
Reference.....	89
Appendix A	
Coverage map prediction simulation procedure.....	94
Appendix B	
Antenna simulation procedure.....	100

LIST OF ABBREVIATIONS

16-QAM	16-ary Quadrature Amplitude Modulation
256-QAM	256-ary Quadrature Amplitude Modulation
64-QAM	64-ary Quadrature Amplitude Modulation
BCH	Bose-Chaudhuri-Hocquenghem multiple error correction binary block code
DVB-T2	Second generation digital terrestrial television broadcasting system
DTT	Digital terrestrial television
DTV	Digital television
EBU	European Broadcasting Union
EPG	Electronic Programme Guide
EWBS	Emergency Warning Broadcasting System
FEF	Future Extension Frame
FFT	Fast Fourier Transform
GI	Guard interval
GA	Genetic algorithms
GE06	Geneva 2006 Agreement.
HD	High definition
ITU	International Telecommunication Unit
MIP	Mega frame Initialization Packet
MFN	Multiple frequency network
MPEG	Moving Pictures Experts Group
OFDM	Orthogonal Frequency Division Multiplex
PLP	Physical Layer Pipe
PPS	pulse per second
PSO	particle swarm optimisation
QAM	Quadrature amplitude modulation
QPSK	Quaternary Phase Shift Keying
QoS	Quality of Service
Rbn	Net Data Rate

<i>Rs</i>	Symbol Rate
RF	Radio Frequency
SADC	Southern Africa Development Committee
SD	Standard Definition
SA	Simulated annealing
SFN	Single frequency network
STB	Set top box
TS	Transport Stream
TV	Television
UHF	Ultra high frequency
VHF	Very high frequency

LIST OF FIGURES

Figure 2.1: Region planning for Digital Terrestrial Broadcasting.....	11
Figure 2.2: UHF spectrum.....	12
Figure 2.3: Digital Terrestrial Television Systems.....	13
Figure 2.4: High level DVB-T2 block diagram.....	14
Figure 2.5 Layer 1 signalling structure.....	15
Figure 2.6: Single Physical layer Pipe.....	17
Figure 2.7: Multiple Physical layer Pipe.....	17
Figure 2.8: PLP type 1 with one slice per T2 Frame.....	17
Figure 2.9: PLP type 2 with several sub-slices per T2 Frame.....	18
Figure 2.10: Modulation pattern.....	18
Figure 2.11: COFDM generation.....	20
Figure 2.12: Pilot Patterns.....	21
Figure 2.13: Rotated and classic Constellations.....	24
Figure 2.14: Coverage area of the transmitter, C/N and Minimum field strength.....	25
Figure 2.15: Multiple Frequency Network topology.....	28
Figure 2.16: Single frequency Network Topology.....	30
Figure 2.17: Reception Site receiving multipath signals.....	31
Figure 2.18: Multipath delay at the Receiver Site.....	32
Figure 2.19: Guard interval.....	34
Figure 2.20: Received signal 5 destructive interferer.....	35
Figure 2.21: Principle diagram of a gapfiller station in SFN mode.....	41
Figure 2.22: STB block diagram.....	42
Figure 2.23: Proposed DTT sites in Zambia.....	44
Figure 2.24: Content distribution network.....	51
Figure 2.25: National DTT management center.....	52
Figure 3.1: (a) Portable TV test receiver.....	56
Figure 4.1: Parameters and antenna patterns (Horizontal and Vertical)	59
Figure 4.2 Lusaka DTT coverage map prediction.....	62

Figure 4.3: Geographical terrain between Lusaka and Kafue.....	63
Figure 4.4: Kapiri Mposhi coverage map prediction.....	64
Figure 4.5: Kapiri Mposhi – Mkushi Path profile.....	64
Figure 4.6: Pemba transmitter coverage prediction map.....	65
Figure 4.7: Senkobo transmitter coverage prediction map.....	66
Figure 4.8: Senkobo and Pemba transmitter radiation patterns and path profile.....	67
Figure 4.9: Kalomo gapfiller transmitter.....	68
Figure 4.10: Kafue – Mazabuka path profile.....	69
Figure 4.11: Lusaka-Chilanga-Kafue single frequency network.....	71
Figure 4.12: Lusaka-Kafue path profile and coverage map prediction.....	72
Figure 4.13: Ndola-Kitwe-Chingola SFN coverage map prediction.....	74
Figure 4.14: Ndola-Chingola path profile.....	75
Figure 4.15: Footprint for Phase 1 DTT implementation in Zambia.....	76
Figure 4.16: Antenna orientation.....	78
Figure 4.17: Portable TV test receiver and standard STB readings.....	82

LIST OF TABLES

Table 2.1: DVB-T2 modulation capacity.....	23
Table 2.2: Rotation angles in DVB-T2.....	25
Table 2.2: C/N QEF Valid for DVB-T2 PP2 32k Normal BW GI 1/8.....	27
Table 2.4: Time properties within the COFDM signal for modes 2k and 8K.....	37
Table 2.5: Fast Fourier Transform and Guard Interval parameters.....	39
Table 2.6: Showing calculation example fill-in transmitter power.....	40
Table 2.7: DVB T2 Operational Modes.....	49
Table 2.8: Phase 1 DTT stations.....	50
Table 4.1: Antenna input parameters.....	59
Table 4.2: Lusaka DTT coverage map prediction Parameter details.....	61
Table 4.3: Lusaka-Chilanga-Kafue SFN parameters.....	70
Table 4.4: Ndola-Kitwe-Chingola SFN parameters.....	73
Table 4.5: Field strength Measurements.....	80

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CHAPTER ONE

INTRODUCTION

1.0 Digital Terrestrial Transmission Background in Zambia

Digital terrestrial broadcasting began in Japan in December 2003 spread rapidly as the world transformed from analogue to digital terrestrial transmission platform. Digital television is described as an advanced television broadcasting technology that has transformed the viewer's viewing experience and provided digital dividends [1].

Digital switchover was seen as a logic consequence of the technological evolution, generating several advantages for citizens and broadcast companies as listed below [2]:

- i. Variety choices and signal quality for viewers (more channels, high-definition television and better image)
- ii. Lower distribution costs and the possibility of transmitting more channels or services at the same cost;
- iii. Greater efficiency in spectrum use i.e. the creation of new services because more data can be transmitted through the same bandwidth;
- iv. Ability to send data that allows interactivity and personalisation.

In summary, digital terrestrial transformation is characterised by reduced utilisation of spectrum and more programme capacity than analogue, a better-quality picture and lower operating costs for transmission.

The worldwide migration from analogue to digital broadcasting complied with the resolution of the International Telecommunications Union (ITU) Regional Radio communication conference (RRC-06) held in 2006 in Geneva, Switzerland. The RRC-06 established the Geneva agreement of 2006 (GE06) whose mandate was to replace existing analogue television broadcasting with digital television broadcasting transmission equipment by 17th June 2015 [3].

The migration from analogue to digital broadcast systems is a most significant drift in television (TV) broadcast. Many countries in Europe and western world have migrated to terrestrial digital TV transmission and, consequently, plan to end analogue broadcasts by ITU deadline. The general membership agreed through the ITU 2006 resolution that the main unique feature that would make

digital television really beneficial and appreciative to end users, is the provision of interactivity, in addition to the pure digital broadcasting of television services.

Digital Terrestrial Television (DTT) is a modern technology, which employs digital modulation techniques for the broadcasting of television services. Programme content flexibility and specific inherent technical advantages put DTT in a significant position to supersede current analogue television systems. The purpose of digital terrestrial television is characterised by reduced utilisation of spectrum and more programme capacity, a better-quality picture, and lower operating costs for transmission after the initial upgrade cost. International standards are in place for DTT, and these are undergoing refinement as the base of understanding and experiencing the technology continue to develop [4].

The RRC-06 established the Geneva Agreement of 2006 (GE06) whereby member countries were required to replace the existing analogue television with digital television broadcasting transmission equipment. However, many countries in the Africa have failed to meet both ITU and SADC resolutions to migrate before the deadline due to some of the following constraints;

- i. Set top box (STB) technical specifications, availability and cost;
- ii. Infrastructure development and sharing;
- iii. Human capital (management, technical and operational);
- iv. Public awareness and campaigns;
- v. Production and availability of content;
- vi. Finance, general funding and economic beneficiation.

1.1 Adoption of DVB T2 and MPEG4 compression for SADC Members

The nine member states constituted by the Southern Africa Development Committee (SADC) were Botswana, Malawi, Mozambique, Swaziland, Namibia, Swaziland, South Africa, Zambia and Zimbabwe. SADC put a special team together to evaluate and determine on digital TV migration processes for the entire region. Under digital television systems that were in consideration were Integrated Services Digital Broadcasting-Terrestrial (ISDB-T), backed by Brazil and Japan, and the two Digital Video Broadcasting (DVB) terrestrial standards (DVB-T and its successor DVB-T2). South Africa, in particular, had been heavily lobbied by Brazil, and its version of the Japanese ISDB standard, much to the chagrin of South Africa's manufacturing community [5].

After months of debate and uncertainty, Southern African Development Community (SADC) digital taskforce chose DVB-T2 with Moving Pictures Experts Group version four compression

(MPEG-4) as the terrestrial transmission standard for the region [6]. SADC ministers, in charge of information and broadcasting in their respective countries, met in Lusaka in November 2010 and endorsed the second generation terrestrial digital video broadcasting (DVB-T2) with MPEG-4 compression as the transmission standard for SADC region. The decision to take on DVB-T2 came amid other choices such as the ISDB-T applied in countries such as Brazil and Japan, after the former adopted and modified the Japanese standard. DVB-T was commonly used throughout Europe and other parts of Africa with MPEG4 compression [7].

Announcing the decision, Committee Chairman, *Joel Kaapanda* pointed at the region's international obligations under the ITU Region 1 Geneva ITU GE06 Agreement and the ITU's 17th June, 2015 deadline for the migration from analogue to digital television. The predecessor of DVB-T was initially accepted by SADC in 2006 and the technological developments into the T2 version were regarded to be superior and factors contributing to the lengthy decision process experienced in the SADC secretarial corridors. It was also assumed that another contributing factor was that of lobbying by some countries like, South Africa, for ISDB-T on behalf of Brazil and Japan [8][9].

The final decision brought relief after concerns were raised when the DVB-T was challenged by DVB-T2, which was superior, as many had already started the migration process. SADC proposed that those already into the process of migration to DVB-T would finally have to switch to the advanced version with many advantages. The regional body recommended to countries that had not started migrating to DVB-T and comply with the region's latest choice of standard of DVB-T2. The statement permitted countries that had already adopted DVB-T to migrate to the new standard, stating that any SADC Member State that resolved to adopt any other standard other than DVB-T2 with MPEG-4 compression should implement it so in compliance with GE-06 Agreement. The statement ruled out any possibility that pockets of ISDB coverage would emerge, because of the difference in channel spacing used by the two systems [10].

1.2 Botswana adopts ISBT standard

On 26 February 2013, Botswana's Minister for Presidential Affairs and Public Administration declared the decision to vary the technology standard that would be used as the country implements the analogue switchover to digital broadcasting [11]. The decision to adopt ISDB-T was a departure from previous commitments to implement DVB-T2 as agreed by SADC members. The principle

behind the decision was likely to be of interest to other African countries formulating their own approach to digital switchover, and would have far-reaching consequences on terrestrial broadcast services in the region. The Government of Botswana announced to adopt the Japanese standard (ISDB-T) as a digital terrestrial broadcasting standard. After Botswana did a series of comparative tests with other standards e.g. DVB-T, DVB-T2 etc, Botswana established and resolved that Japanese standard had more advantages such as capability to broadcast both digital terrestrial television and mobile broadcasting from the same transmitter and became the first country that adopted ISDB-T in Africa and contrary to the SADC decision. Botswana positioned priority on the digital migration as a fundamental infrastructure and set a target of digital migration in June 2015 according to the Geneva 2006 (GE06) Agreement [11].

However, Botswana did not have enough technological knowledge and expertise on ISDB-T standard that was developed in Japan. ISDB-T had advantageous features that were not offered by other standards, such as the mobile broadcasting service called one-seg, data broadcasting and the emergency warning broadcasting system (EWBS), and was projected that making full use of additional functions would contribute to the social and economic development of Botswana [12]. One-seg service endowed people to watch television even in those areas where access to the power supply was difficult, with a small set of television that worked with batteries. The service expected to narrow the information gap between rural and urban areas. Data broadcasting provided access to the information such as weather pattern, traffic information and television programs whenever necessary by the television. EWBS could transmit warning message in time of disaster in a prompt manner that could preserve the lives of people [13].

1.3 Zambia DVB - T2 standard adoption

Reaffirming the ITU and SADC recommendations and resolutions, on 28th May, 2012, Government of the Republic of Zambia endorsed and adopted DVB-T2 and MPEG-4 as national standards in line with SADC resolution. The Government's objective was countrywide roll out of at least seventy-three (73) DTT transmission sites to cover the entire Zambia. High power transmitters were to be installed along the line of rail, namely Kitwe, Kapiri Mposhi, Lusaka, Pemba and Senkobo. Medium power transmitters were to be installed in provincial centers, namely, Chipata, Chinsali, Mansa, Solwezi, Mongu, Livingstone and Kasama. Low power transmitters in all districts across Zambia. The National Task Force (NTF) on digital migration

was set-up by the Zambian government to make recommendations and generally oversee the national digital migration process. The operations of the task force were to be managed by a national steering committee which composed of Ministry of Information and Broadcasting Services (MIBS), Zambia Information Communications and Telecommunication Authority (ZICTA), Zambia National Broadcasting Corporation, (ZNBC) and some private media organisations.

The NTF was tasked by MIBS, among other terms of reference, to facilitate the creation of independent signal distributor(s) to provide signal distribution services to all licensed broadcasters and development of clear terms, conditions and tariff framework for infrastructure sharing and fair competition among operators in the broadcast industry.

The ushering in of DTT in the broadcasting industry has clearly shown that analogue has become absolute in the broadcast industry. It is a fact that there are many factors that are likely to affect digital migration in Zambia, care must be taken to ensure adequate preparation and implementation are done to overcome such challenges before the actual analogue switch off.

1.4 Implementation challenges

The Broadcasting sector has been evolved in terms of service production, transmission platform and reception devices in the last few decades. It has encountered many universal challenges, and because it is not optional, most countries have been seen firefighting to achieve goals. Digital migration develops with challenges ranging from lack of proper awareness creation through to deadline issues and finally, to unexpected outcomes.

In Kenya, the deadline posed a technical challenge due to unpreparedness of media houses, media regulators, and the government itself. The Kenyan leading media houses namely; Nation Media Group, Standard group and the royal media services, complained that the deadline was so close for them and contended that the installation of digital infrastructure was too expensive to be done promptly [14]. Secondly, there was also the financial challenges that confronted both the media stations and the government. Thirdly, the government had limited resources to implement protracted sensitization campaign. Fourthly, the government policies on digital migration were an obstacle in digital migration. The migration policy was considered unfriendly to private media houses because of politics and misinformation, this resulted into a prolonged court litigation, and

further, delayed the process. The Government did not sufficiently inform the citizens enough on where and how the process began, the difference between digital and analogue television transmissions, the challenges of digital migration, the benefits of digital broadcasting, the methods of accessing digital content after migration, the implications of digital migration on different sectors and how impact would be on media industry. Almost all countries including Zambia faced similar challenges as highlighted in the Kenyan situation [15] [16].

Tanzania adopted the DVB-T2 standard for digital terrestrial broadcasting. Three multiplexer (MUX) operators, namely; Star media, Basic Transmission Limited and Agape Associates Limited have been licensed in Tanzania. The operators have chosen to offer combined FTA and conditional access services by allocating space in each frequency channel. However, it has been difficult for the three players to accept using a common cooperation platform to offer services to its customers. Hence, each MUX operator has opted for different brand of scrambling algorithm. This is not surprising since in other countries that have completed deployment of terrestrial digital broadcasting have gone through the same experience. The problem has been there for cable and satellite broadcasting services in many countries [20].

1.5 Statement of the problem

The analogue television system has been in existence in Zambia over the years. Nevertheless, the analogue broadcasting techniques has contributed its own quota to the development of broadcasting industry in Zambia and cannot be overemphasized. With the advent of the digital transmission technology which will revolutionise broadcasting industry in Zambia and set to be a technical solution to the many technical challenges inherent in the analogue terrestrial system. It is absolutely necessary to correct those proficient anomalies, analyse and evaluate digital terrestrial television coverage and transitional implications as well as the benefits of the digital television technique over the analogue transmission system in Zambia. It is pertinent to disclose that digital technology has brought about qualitative signal processing, reception, reach and digital dividends which were never present in the analogue broadcasting era.

Thus, this work seeks to examine the technical benefits, effectiveness of the Single and Multiple Frequency Networks television coverage in view of uneven Zambian terrain, digital television footprint, reception and also, transitional challenges of DTT implementation in Zambia.

1.6 Research questions

The following research questions were raised to give this research work a direction. They include:

- 1.14.1 Why is Zambia adopting digital television?
- 1.14.2 What is the optimal application of Single and Multiple Frequency Networks for DTT coverage in Zambia?
- 1.14.3 What is the signal field strength in the DTT coverage areas in order to provide signal footprint in Zambia?
- 1.14.4 What recommendations should be made to overcome identified technical challenges in order to attain full signal coverage of Phase 1 implementation of DTT in Zambia?

1.7 Objectives of the project

Digital terrestrial and satellite transmission modes are currently being deployed in Zambia. The focus of this dissertation will be on evaluation of digital terrestrial broadcasting in Zambia which includes carrying out detailed DTT implementation plan analysis, particularly, Single Frequency Networks (SFN) and Multiple Frequency Network (MFN) applications in order to provide optimal signal coverage of Phase 1 DTT implementation in Zambia. And also determination of signal field strength, modulation and bitrate errors in the areas under consideration.

1.8 Specific Objectives of the dissertation

The specific objectives of the study among other things will be:

- 1.9.1 To analyse the DTT implementation plan in Zambia
- 1.9.2 To evaluate the optimal application of Single frequency Network and Multiple Frequency Network for full coverage of DTT in Zambia
- 1.9.3 To examine the signal footprint of DTT coverage in Zambia
- 1.9.4 To determine the signal field strength (SFS) in some areas.

1.9 Research Methodology

Relevant technical data was obtained from the Ministry of information and Broadcasting Services, the overseer of digital television implementation process in Zambia such transmission site positions and transmitter parameters per site such as transmitter power, network system to be used, etc.

At the receiver terminal, several values i.e. signal field strength, modulation error, bitrate error were taken by the portable TV test receiver and distances from the transmitters by GPS instrument. The WRAP software management tool was used to generate coverage prediction maps from a number of transmitters to give full coverage in the region and also to determine signal strength at receiver. The measured values using the portable TV test receiver and coverage map prediction propagation models were analysed and compared.

In terms of professional standards, the researchers ensured that the data were gathered in a professional manner without misrepresenting facts and/or intentionally misleading the outcome about the nature of the study. The researchers ensured that all the findings were presented honestly without fabricating any data to support any particular finding. The researchers also adhered to the institutional guidelines on conducting research.

1.10 Relevance

The relevance of this study will be to evaluate various technical factors that will enable a full DTT coverage and footprint in Zambia, specifically:

- 1.11.1 The application of Single and Multiple Frequency Networks in order to optimize signal coverage across the country in view of uneven and complex terrain.
- 1.11.2 The tradeoff between bitrate and robustness
- 1.11.3 The usage of the National headend in order to provide a multicarrier platform for different content providers
- 1.11.4 The signal distribution network via the National Headend to the respective transmitting sites and Direct-To-Home (DTH) receivers in Zambia
- 1.11.5 The DTT signal reception in Zambia in view of terrestrial and direct-to-home via satellite transmissions.

1.11 Scope of Study

The scope of the study will be to evaluate detailed plan for Digital terrestrial television (DTT) implementation in Zambia in line with the International Telecommunications Union (ITU) treaty. Zambia's implementation process has been segmented into three, namely, Phase 1, Phase 2 and Phase 3, respectively. Phase 1 covers the line of rail, i.e. from Chililabombwe to Livingstone. Phase 2 and 3 are yet to be implemented at the same time in Provincial and district centers, respectively.

The thesis scope will be to evaluate digital terrestrial transmission of Phase 1 which includes carrying out detailed analysis of Single and Multiple Frequency Networks taking into account the topography of the terrain, Bit Error Rate (BER), Signal Field Strength (SFS) and Modulation Error Rate (MER) in selected areas. Also in the analysis of Phase 1 DTT implementation, focus will be on the footprint of DTT coverage to determine the quality of service delivered and further make appropriate recommendation for system improvement.

1.12 Research contributions to the body of Knowledge

The unique contribution to knowledge made in this study is through the critical analysis of modern digital TV transmission system in Zambia. New technical transmission model, information and insight of DTT implementation plan are obtained through the critical analysis of Single and Multiple Frequency networks, and also, signal field strength analysis in view of Zambia's geographical terrain. Considerably, this work is the first of its kind for the Zambian environment and uncovers new technical knowledge regarding digital terrestrial TV transmission. Furthermore, the work presented gives evaluation of DTT implementation plan, analysis of Single and Multiple frequency networks deployment and also technical benefits of digital television in Zambia. Finally, the work will enlighten the technical challenges that are associated with digital television transmission implementation process.

1.13 Dissertation Organization

This dissertation is organized as follows; Chapter One describes the ITU resolution, the introduction of digital terrestrial transmission (DTT) in Zambia, motivation of this research work, research questions, the research setting and methodology. A comprehensive review of available DTT literature and reviews of some prominent works done by other researchers in digital television transmission are, comprehensively, discussed in Chapter Two including the overview of DTT implementation in Zambia. The main features, parameters and settings of the heuristic WRAP software management tool employed to carry out the optimisation of simulated coverage map predictions are described in Chapter Three. Furthermore, a detailed description of the approach proposed to optimize the coverage map prediction of SFN and MFN taking into account the orography of the Zambian terrain, technical specifications for both transmitter and receiver sides, alongside with Single and Multiple Frequency Network application requirements, is articulated in

the same Chapter Three. Data collection and result analysis examining the coverage map prediction and DTT footprint in comparison with the actual signal field strength measurements are summarised and discussed in Chapter Four. Finally, the main discussion and conclusion of the research work are outlined in Chapter Five and also, makes appropriate recommendations for some challenges to be resolved in the implementation of digital television across Zambia.

1.14 Summary

The chapter started by outlining the basic background and the importance of digital migration in Zambia. This chapter further indicated that digital television has more advantages and important features than analogue; however, there are still some fundamental issues of accessibility which are likely to hamper the progress of digital TV roll-out in Zambia. Also discussed were some challenges that most of countries have encountered in the implementation of digital television, which include technological shift, financial constraints, infrastructure and human resource development, etc. The research problem also identified some of the technical issues that are worth investigating through research of this nature. The motivation for conducting the research and research questions to be attempted and answered in the research were provided in this chapter. In concluding, the chapter also provided a preview of adoption process of DVB T2 and MPEG4 compression for SADC Members which included Zambia except for Botswana which preferred to adopt ISBT standard.

In relation to the contextualization of a research problem, the next chapter will discuss literature review of theoretical frame work of DVB-T2, modulation, Single and Multiple Frequency network theory and reception of digital television signal.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The Regional Radio Communication Conference (RRC-06), which was held in Geneva in 2006 had the objective to produce a plan for digital terrestrial broadcasting in the 174-230 MHz and 470-862 MHz of the television spectrum in order to create digital dividend. The world was divided into regions as shown in Figure 2.1. This comprised parts of Region 1, west of 170 degrees eastern longitude including the territories of the Islamic Republic of Iran, but excluding the territory of Mongolia. Of the 120 member states with territories in the planning area, 93 were represented by 782 delegates during the conference. [17]

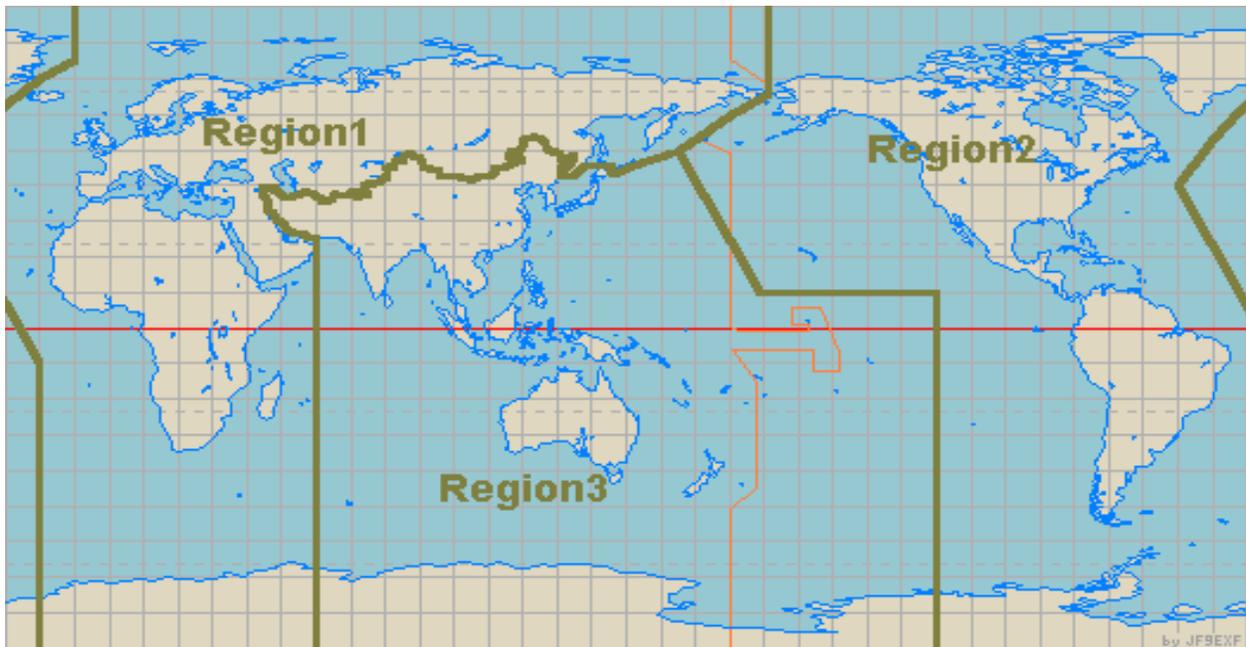


Figure 2.1: Region planning for Digital Terrestrial Broadcasting [17]

The most recent ITU World Radio Communication Conference (WRC-12) opened the door for allocation of the 700 MHz band between 694 and 790 MHz to the mobile service at the end of 2015 in ITU Region 1. It also agreed to identify frequency bands to satisfy additional spectrum requirements for the mobile service. WRC-07 made a previous allocation of the 800 MHz band between 790 and 862 MHz to the mobile service. Nevertheless, it is in the process of being released from broadcasting in Europe [18]. Figure 2.2 shows the segmentation of UHF frequency band.

Digital television is allocated channels 21- 49 (470 -694MHz) and mobile service channel 50 – 60 (695-798MHz).

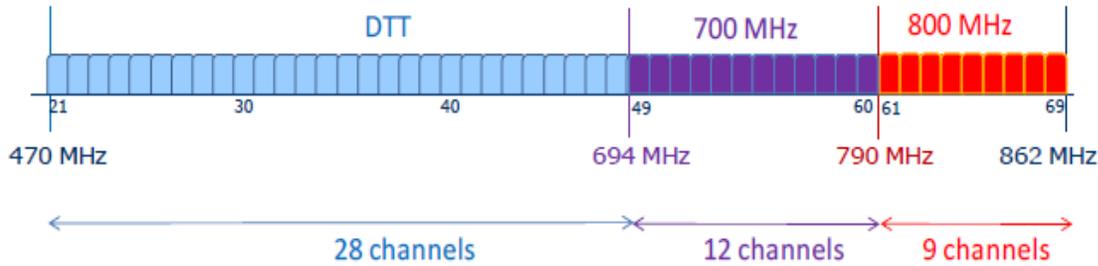


Figure 2.2: UHF spectrum [18]

The challenge for ITU Members is to continue rendering their free-to-air content to the widest possible audience with easy access to terrestrial broadcasting platform. This platform combines technical quality, cost efficiency and the ability to deliver free-to-air services. Reducing the spectrum available for terrestrial broadcast delivery will affect one or more of these criteria and may result, ultimately, in the fading out of this delivery. Investments made so far by broadcasters in DTT networks and by consumers in DTT receiving equipment need to be preserved for a sufficiently long time. Moreover, sufficient spectrum resources for upgrading to high definition and, eventually, ultra-high definition TV services are needed [19].

Furthermore, such new technologies need to be introduced in parallel with the existing ones to allow consumers to invest in new equipment according to their wishes, while the existing services are maintained during a transition period with simulcast transmissions. DTT technology and services can be expected to further develop in the future, thus creating recurrent needs for upgrades and simulcast of existing services. Guaranteed access to this spectrum is needed to provide certainty to broadcasters and the industry alike and encourage further standardisation work and investments in enhanced technologies for service delivery. Keeping full and exclusive access to the current broadcasting bands would be the best outcome. However, regional and national decisions might result in a release of the 700 MHz band by broadcasting after a certain period of time [20].

2.1 Adoption and Standards

Digital television is the transmission of digitally processed and multiplexed television signal, in contrast to the total analogue and channel separated signals used by analogue broadcast.

Many countries are superseding analogue television broadcast with digital television to facilitate commercial use of the television radio spectrum or digital dividend. Regions of the world have adopted different broadcasting standards as shown in Figure 2.3.

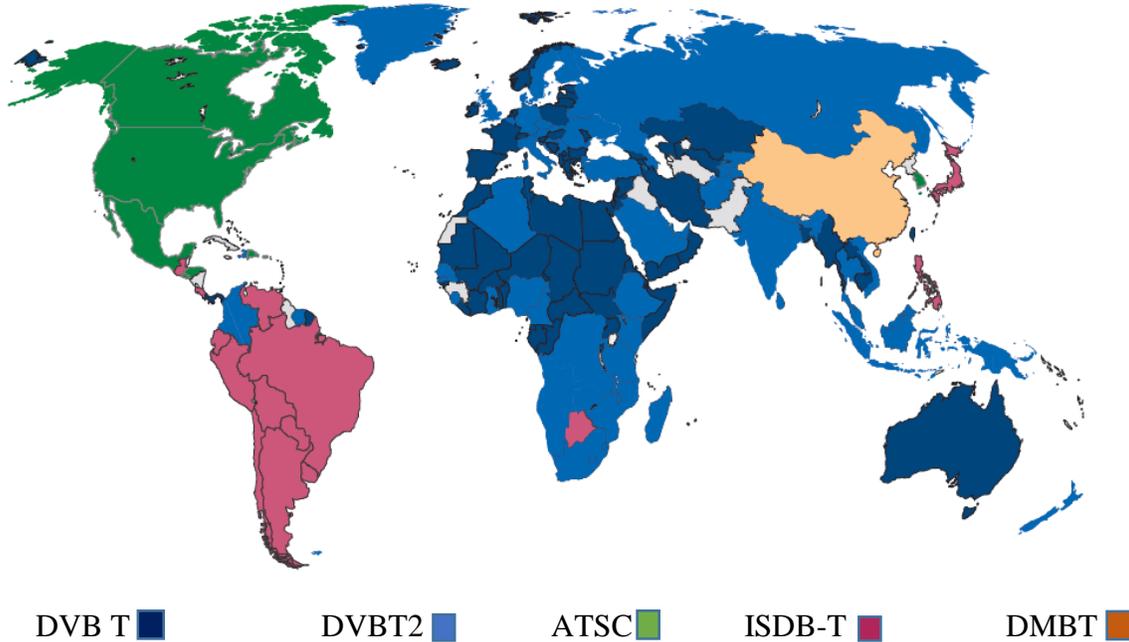


Figure 2.3: Digital Terrestrial Television Systems [21]

In Figure 2.3, deep blue indicates countries that have adopted or deployed DVB-T and light blue shows DVB-T2 standards, respectively. The green part represents North America and South Korea which adopted advanced television systems committee for digital TV transmission (ATSC). Europe, Australia, New Zealand, Colombia, Uruguay and some African countries adopted Digital Video Broadcasting-Terrestrial (DVB-T/DVB-T2) while China preferred Digital Multimedia Broadcast-Terrestrial/Handheld (DMB-T/H). On the other hand, Japan, Brazil and Peru opted for Integrated Services Digital Broadcasting-Terrestrial (ISDB-T) as shown by red colour, with similarities to DVB-T and capable of sharing front-end receiver and demodulator components and techniques. However, some countries remain, mostly, undecided on which DTT standard to adopt and implement [21].

The digital switchover process is well underway worldwide. A lot of countries in Europe and western countries have already completed the analogue switch off (ASO). The process of analogue switch-off (ASO) differs from country to country depending on the goals of ASO and upon the market configuration (percentage of terrestrial reception). While ITU region 1, GE-06 had set the precise date of 17 June 2015 as the end of the transition period, the SADC members resolved to

switch over to digital terrestrial television (DTT) by 31st December 2013. However, most member states have failed to meet the SADC deadline for the reasons indicated in Chapter one. For example, Zambia set 31st December 2014 as a date by which analogue terrestrial television transmission should be switched off and migrated to DTT platform. However, test DTT transmission commenced on 5th January, 2015 in Zambia with only partial digital television transmission between midnight and 10:00hrs the following day [21].

2.2 DVB-T2 Standards

DVB-T2 is the world’s most advanced digital terrestrial TV system, offering more robustness, flexibility and at least 50% more efficiency than DVB-T system. It supports standard definition (SD), high definition (HD), ultra-high definition (UHD), mobile TV, or any combination thereof. The generic block diagram of DVB-T2 is represented in Figure 2.4. The system input(s) maybe one or more MPEG-2 or MPEG-4 transport stream(s) and one or more generic stream(s) [22]. The input pre-processor, which is not part of the DVB-T2 system, may include a service splitter or demultiplexer for transport streams (TS) for separating the services into the DVB-T2 system inputs, which are one or more logical data streams that are carried in individual physical layer pipes (PLPs). The system output is typically a single signal to be transmitted on a single radio frequency (RF) channel. Optionally, the system can generate a second set of output signals, to be conveyed to a second set of antennas in what is called Multi Input Serial Output (MISO) transmission mode [16].

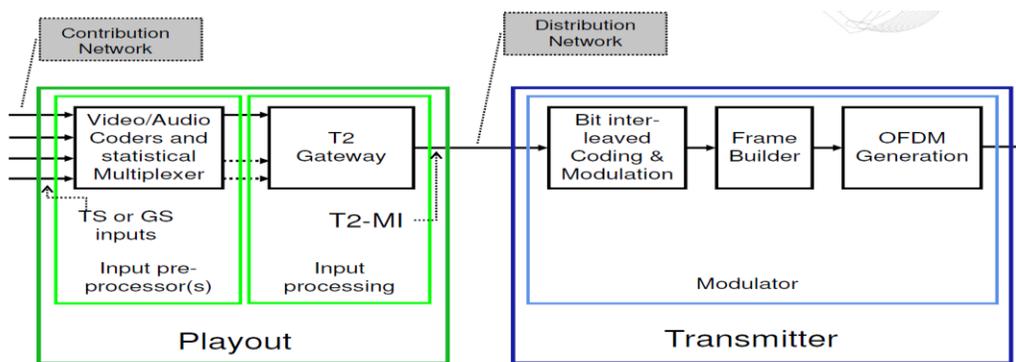


Figure 2.4: High level DVB-T2 block diagram [22]

2.2.1 Technical features of DVB-T2 Architecture

DVB-T2 is a transmission standard in the physical layer of OSI standard and offers 30-50% more capacity than the initial DVB-T standard. DVB-T2 is a second generation terrestrial broadcast

transmission system that was initiated by DVB project. The main purpose was to increase capacity, ruggedness and flexibility to the DVB-T system. Compared to DVB-T, DVB-T2 COFDM parameters have been extended to include [23]:

- i. New generation forward error correction (FEC) and protection
- ii. Higher constellations (256-QAM) resulting in a capacity gain of 25-30%, approaching the Shannon limit.
- iii. OFDM carrier increase from 8k to 32k. In SFN, the guard interval of 1/16 instead of 1/4 resulting in an overhead gain of 18%.
- iv. New guard interval fractions: 1/128, 19/256, 19/128.
- v. Scattered pilot optimisation according to the guard interval, continual pilot minimization resulting in an overhead reduction of 10%.

2.2.2 Generation, Coding and Modulation of Layer 1 Signalling

The layer 1 (L1) signalling provides the receiver with a means to access physical layer pipes within the T2-frames. Figure 2.5 illustrates the L1 signalling structure, which is split into three main sections: the physical layer pipe (P1) signalling, the L1-pre signalling and L1-post signalling.

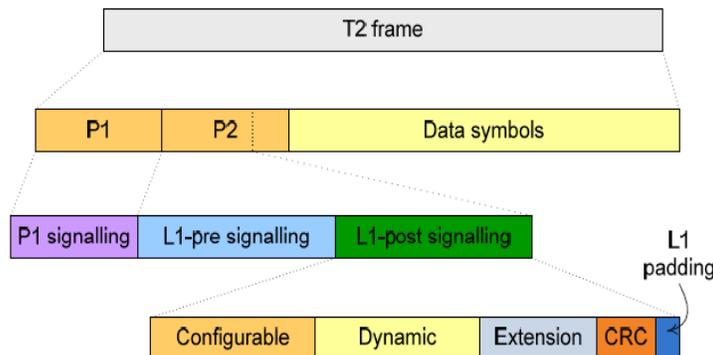


Figure 2.5: Layer 1 signalling structure [24]

The purpose of the P1 signalling which is carried by the P1 symbol, is to indicate the transmission type and basic transmission parameters such as timing, frequency offset, and Fast Fourier transform size (FFT-size). The remaining signalling is carried by the P2 symbol(s), which may also carry data that is the same FFT-size and guard interval as the data symbols. Layer one pre-signalling enables the reception and decoding of the L1-post signalling, which in turn conveys the

parameters needed by the receiver to access the physical layer pipes [24]. The L1 signalling is divided into L1-pre-signalling and L1-post signalling. The modulation and code rate of the L1-pre-signalling is BPSK 1/2 and the number of signalling bits in L1 pre-signalling is constant. Thus, the L1-pre signalling always occupies 1 840 cells. The number of signalling bits in L1-post signalling depends on the number of PLPs number of auxiliary streams. The number of cells occupied by the L1-post signalling depends on the number of signalling bits and modulation used [25]. The L1-post signalling can be modulated using BPSK, QPSK, 16-QAM or 64-QAM. The forward error correction (FEC) code rate is always 1/2. The modulation for the L1-post signalling is chosen so that the L1 signalling is always more robust than any physical layer pipe (PLP).

Thus, the number of PLPs that can be carried by the T2 system is limited by the modulation used for L1-post signalling and the number of signalling bits [26].

2.2.3 Physical Layer Pipes (PLP)

The PLP concept is inherited from the DVB-S2 standard. It allows service-specific robustness. Every PLP can have its own modulation, FEC code rate and interleaving. All PLPs are broadcast over the same frequency so that there are considered as a single DVB-T2 stream. A DVB-T2 multiplex can carry a single PLP, defined as input mode A, or multiple PLP, defined as input mode B of the T2 system. A T2 system can broadcast a maximum of 255 PLP per multiplex. Mode A is a single PLP indicating Playout and distribution similar to DVB-T2 as shown in Figure 2.6.

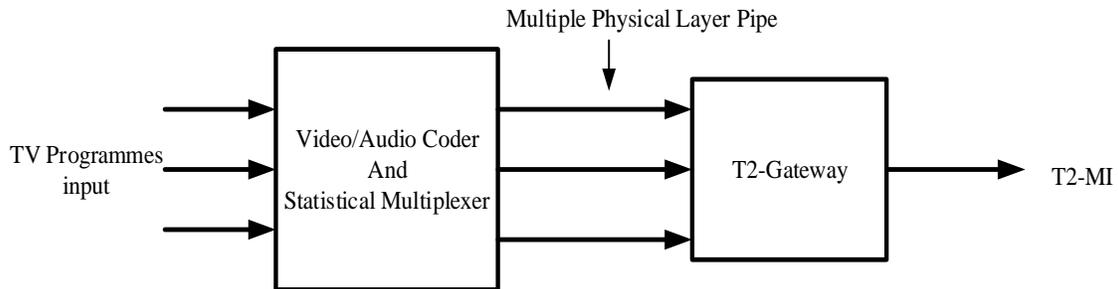


Figure 2.6: Single physical layer pipe

Mode B is multiple physical layer pipes providing playout and distribution of more complex signal as shown in Figure 2.7. It allows for service-specific robustness. Every PLP can have its own modulation, FEC code rate and interleaving. All PLPs are broadcast over the same frequency so that they are considered as a single DVB-T2 channel. There are three types of PLP;

- i. PLP of type 0 that carries information extracted from the other data PLP such as program guide, or other common information.
- ii. PLP type 1 contains 1 slice per T2 frame while type 2 contains several slices to carry the actual data [27].

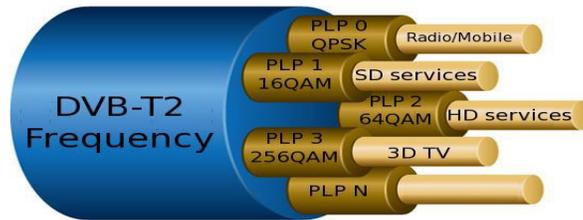


Figure 2.7: Multiple Physical layer Pipe [12]

The data PLP of type 1 can be used for services that require a good power saving as shown in Figure 2.8.

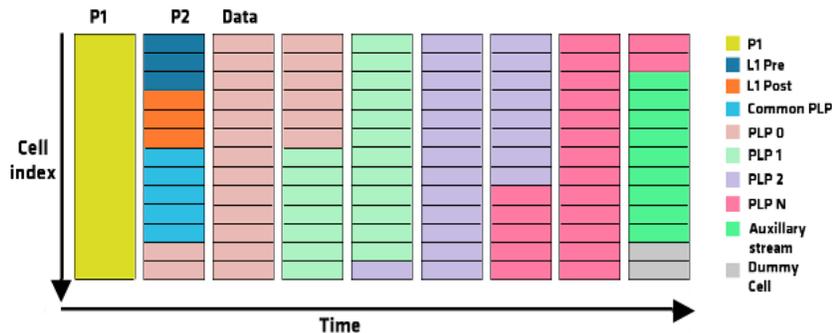


Figure 2.8: PLP type 1 with one slice per T2 Frame [27]

In Figure 2.9, the data PLP of type 2 is carried in multiple sub-slices per T2 frames increasing time diversity and then providing better robustness for mobile services. The number of sub-slices should be as large as possible.

In M-PLP mode, the demodulator shall receive at the same time the common PLP and one data PLP to be able to build the MPEG-2 Transport Stream as it is received at the input of the PLP builder. The demodulator can be tuned to the desired PLP with regard to the information extracted from the SI tables or retrieved from the scanning. As the demodulator is supposed to read only one PLP at a given time there is no limitation in the receiver side on the number of supported PLP [27].

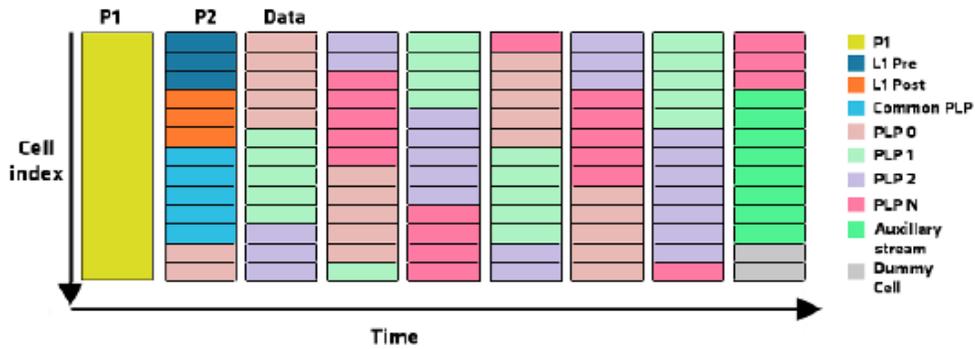


Figure 2.9: PLP type 2 with several sub-slices per T2 Frame [27]

Some parameters are common to all PLP, such as central frequency, SFN/MISO, bandwidth, guard interval, FFT size or scattered pilot pattern. And some parameters are PLP specific such as constellation, code rate, FEC, TS bit rate and time interleaving depth. The DVB-T2 utilises 256-QAM modulation pattern as shown in Figure 2.10.

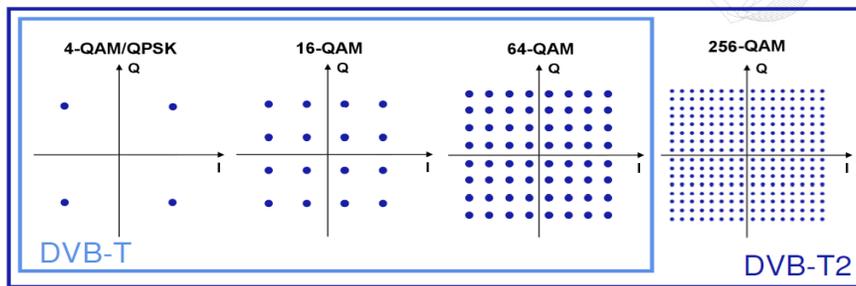


Figure 2.10: Modulation pattern [22]

Combinational of various modulation schemes with Fast Fourier Transform (FFT) sizes and guard intervals allows construction of MFN and SFN networks designed for different applications: from low bit-rate but robust mobile reception to the high bit-rate fixed reception for domestic and professional use [28].

2.2.4 Coded Orthogonal Frequency Division Multiplexing Generation

Orthogonal Frequency Division Multiplex (OFDM) is a multi-carrier method with thousands of subcarriers, which do not interfere with each other because they are orthogonal to one another.

The multicarrier OFDM modulation technique offers a robust mechanism against frequency selective fading and narrowband interferences in multipath radiation. On the one hand, the aim of dividing the information to send into several orthogonal subcarriers is to alleviate the co-channel interference, trying to reduce the impact on the quality of a small information loss at the receiver

side by means of error control techniques. On the other hand, the ISI is decreased by copying the initial or final part of the OFDM symbol during the guard interval or applying other techniques, such as using a suitable synchronization strategy for the fast Fourier transform (FFT) window positioning at the receiver side or delaying the symbol transmission from transmitters [28][29]. The information to be transmitted is distributed and interleaved to many subcarriers, firstly having added the appropriate error protection, resulting into coded orthogonal frequency division multiplex (COFDM). Each of these subcarriers is a vector modulated, i.e. QPSK, 16QAM, 64QAM or 256QAM modulated. All subcarriers are spaced apart by a constant interval. Any communication channel can contain up to a thousands of subscribers, each of which could carry the information from a source which would have nothing to do with any of the others at all [30]. However, it is also possible to provide a common data stream with error protection and then divide it into the many subcarriers. This is frequency multiplexing. The generation of COFDM is illustrated in Figure 2.11.

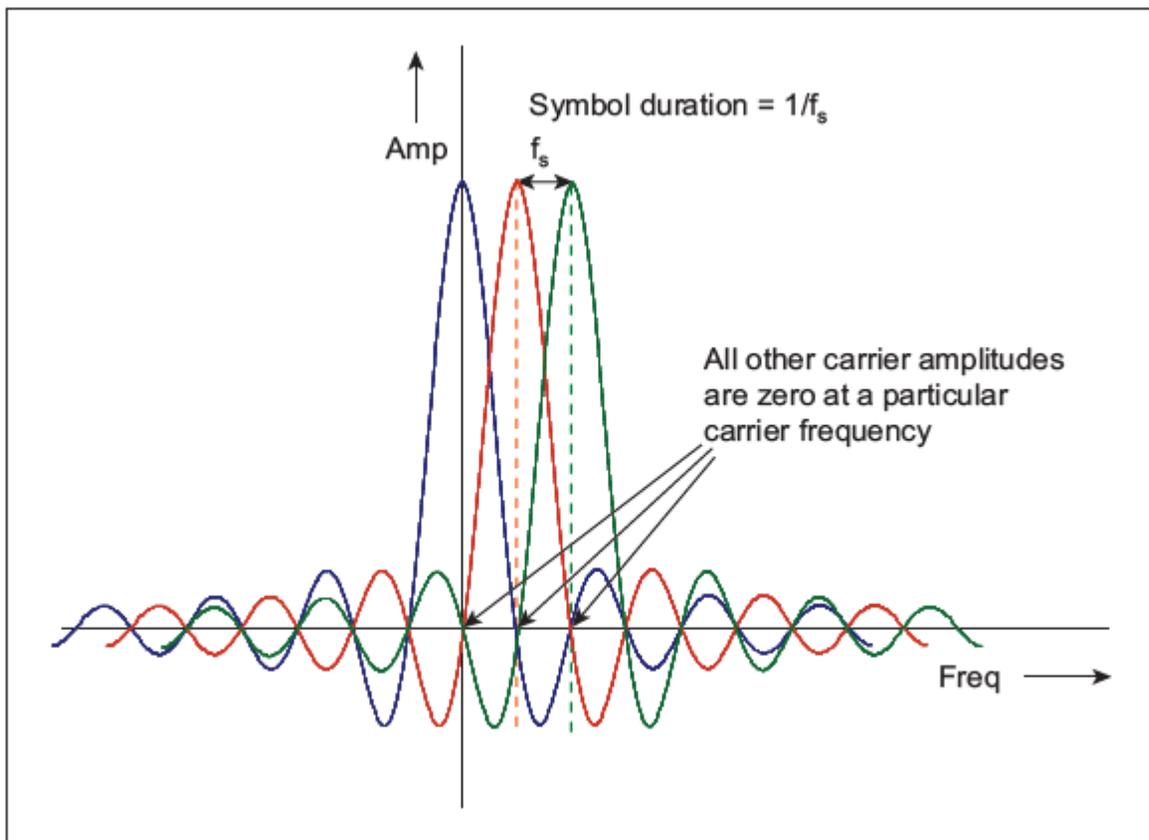


Figure 2.11: OFDM Spectrum [22]

The carrier spacing is uniform and deliberately chosen so that it is the inverse of each symbol duration. This choice of carrier spacing ensures orthogonality of the carriers which means that the influence of adjacent carriers (in fact all other carriers) on the demodulation of a particular carrier is zero. It ensures there is no crosstalk between carriers, even though there is no explicit filtering and their spectra overlap [29] [30].

The use of OFDM in DVB-T2 systems, exploiting the ability of the OFDM receivers to work in multipath environments assists to mitigate those effects. The multicarrier OFDM modulation technique renders a robust mechanism against frequency selective fading and narrowband interferences in multipath environments. On the one hand, the objective of dividing the information to transmit into several orthogonal subcarriers is to mitigate the co-channel interference and minimise the impact on the quality of a small information loss at the receiver side by means of error control techniques, for instance forward error correction techniques. On the other hand, the ISI is minimised by copying the initial or final part of the OFDM symbol during the guard interval or applying other techniques, such as using a suitable synchronization strategy for the fast Fourier transform (FFT) window positioning at the receiver side or delaying the symbol transmission from transmitters [37].

2.2.5 Choice of Parameter for DVB-T2

2.2.5.1 Choice of Pilot Pattern

Pilots are carriers which do not contain net information but serve for transmission purposes such as channel estimation, equalization, common-phase-error correction and synchronization. Of the different kinds of pilots such as continual, scattered, P2 and frame-closing pilots, only the scattered pilots can be changed. Scattered pilots are used by the DVB-T2 receiver to make measurements of the channel and to estimate the channel response for every OFDM cell so that distortions in the received signal may be corrected. The measurements, and hence pilot density, need to be sufficiently high so that they can follow channel fluctuations as a function of both frequency and time as shown in Figure 2.12.

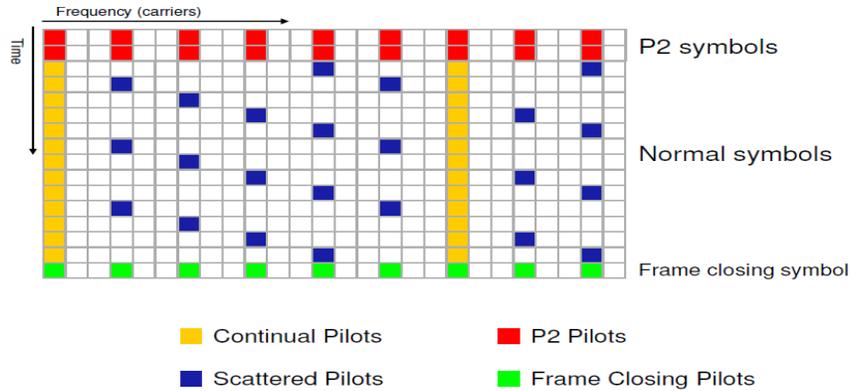


Figure 2.12: Pilot Patterns [31]

In DVB-T2, eight different pilot patterns are available, i.e. PP1 to PP8. As certain patterns are more suited to particular channel types than others, the range in pilot patterns gives the network planner more freedom to match the transmission mode and pilot patterns to the intended transmission channel or payload requirement.

Scattered pilots of pre-defined amplitude and phase are inserted into the signal at regular intervals in both time and frequency directions. All of the pilots can potentially be used for synchronization. The scattered, P2 and frame-closing pilots can be used for channel estimation. The continual, P2 and frame-closing pilots can be used for common-phase-error correction. DVB-T has only one pattern, DVB-T2 has different pilot patterns (PP1-PP8) and are defined depending on FFT size and guard interval. The dense PP means better channel estimation and less data rate. It should be noted that not all PPs are available for all T2 configurations (Mode and guard interval) [31].

The worst condition occurs when two signals from two transmitters arrive with the same amplitude at the receiver. In this case, the channel frequency response of the received signal presents a periodic fading pattern which is frequency dependent on the inverse of the relative delay between echoes. The impact on the receiver will depend strongly on the pilot pattern and on the channel estimation algorithm. Pilot pattern 8 requires the receiver to employ a channel equalization strategy that is fundamentally different to the others PP8, in that channel estimation is based on the data rather than the pilots. No receivers are known to have incorporated this mode, largely due to the additional complexity required in the receiver. Therefore, before settling on this pattern, receivers intended for the service should be confirmed to support it. Furthermore, PP8 has some limitations over the others that should be considered. PLPs are not

supported in PP8, and time interleaving should not be used. The latter means that the vastly improved impulse resilience of DVB-T2, an important benefit, cannot be realized [31].

Table 2.1 shows the selection of parameters for modulation, code rate, guard interval and scattered pilot pattern to be used in either single or multiple frequency network transmission.

Table 2.1: DVB-T2 modulation capacity [13]

Modulation	Code rate	Scattered Pilot Pattern 5 & 6							Scattered Pilot Pattern 7 & 8						
		GIF							GIF						
		1/128 [Mbit/s]	1/32 [Mbit/s]	1/16 [Mbit/s]	19/256 [Mbit/s]	1/8 [Mbit/s]	19/128 [Mbit/s]	1/4 [Mbit/s]	1/128 [Mbit/s]	1/32 [Mbit/s]	1/16 [Mbit/s]	19/256 [Mbit/s]	1/8 [Mbit/s]	19/128 [Mbit/s]	1/4 [Mbit/s]
QPSK	1/2	7.3	7.1	6.9	6.8	6.5	6.4	5.9	7.3	7.2	7.0	6.9	6.6	6.4	5.9
	3/5	8.7	8.5	8.3	8.2	7.8	7.7	7.0	8.8	8.6	8.4	8.3	7.9	7.7	7.1
	2/3	9.7	9.5	9.2	9.1	8.7	8.5	7.8	9.8	9.6	9.3	9.2	8.8	8.6	7.9
	3/4	10.9	10.7	10.4	10.2	9.8	9.6	8.8	11.0	10.8	10.5	10.4	9.9	9.7	8.9
	4/5	11.6	11.4	11.1	10.9	10.4	10.2	9.4	11.8	11.5	11.2	11.0	10.6	10.3	9.5
	5/6	12.1	11.9	11.5	11.4	10.9	10.7	9.8	12.3	12.0	11.6	11.5	11.0	10.8	9.9
16-QAM	1/2	14.6	14.2	13.8	13.7	13.1	12.8	11.8	14.7	14.4	14.0	13.8	13.2	12.9	11.9
	3/5	17.5	17.1	16.6	16.4	15.7	15.4	14.1	17.7	17.3	16.8	16.6	15.9	15.5	14.3
	2/3	19.5	19.0	18.5	18.3	17.5	17.1	15.7	19.7	19.2	18.7	18.5	17.6	17.3	15.9
	3/4	21.9	21.4	20.8	20.6	19.6	19.2	17.7	22.1	21.6	21.0	20.8	19.9	19.5	17.9
	4/5	23.4	22.9	22.2	21.9	21.0	20.5	18.9	23.6	23.1	22.4	22.2	21.2	20.8	19.1
	5/6	24.4	23.8	23.1	22.9	21.9	21.4	19.7	24.6	24.1	23.4	23.1	22.1	21.6	19.9
64-QAM	1/2	21.8	21.3	20.7	20.5	19.6	19.2	17.6	22.0	21.5	20.9	20.7	19.8	19.4	17.8
	3/5	26.2	25.6	24.9	24.6	23.5	23.0	21.2	26.5	25.9	25.1	24.9	23.8	23.3	21.4
	2/3	29.2	28.5	27.7	27.4	26.2	25.6	23.6	29.5	28.8	28.0	27.7	26.4	25.9	23.8
	3/4	32.8	32.1	31.1	30.8	29.4	28.8	26.5	33.2	32.4	31.5	31.1	29.7	29.1	26.8
	4/5	35.0	34.2	33.2	32.9	31.4	30.8	28.3	35.4	34.6	33.6	33.2	31.7	31.1	28.6
	5/6	36.5	35.7	34.6	34.3	32.7	32.1	29.5	36.9	36.1	35.0	34.6	33.1	32.4	29.8
256-QAM	1/2	29.1	28.5	27.7	27.4	26.1	25.6	23.5	29.5	28.8	27.9	27.6	26.4	25.9	23.8
	3/5	35.0	34.2	33.2	32.9	31.4	30.8	28.3	35.4	34.6	33.6	33.2	31.7	31.1	28.6
	2/3	39.0	38.1	37.0	36.6	34.9	34.2	31.5	39.4	38.5	37.4	37.0	35.3	34.6	31.8
	3/4	43.8	42.9	41.6	41.2	39.3	38.5	35.4	44.3	43.3	42.0	41.6	39.7	38.9	35.8
	4/5	46.8	45.7	44.4	43.9	41.9	41.1	37.8	47.3	46.2	44.9	44.4	42.4	41.5	38.2
	5/6	48.8	47.7	46.3	45.8	43.7	42.8	39.4	49.3	48.2	46.8	46.3	44.2	43.3	39.8

2.2.5.2 Choice of Rotated Constellations

In a non-rotated constellation, the receiver requires both in-phase (I) and quadrature (Q) components of one constellation point to recognise what information was transmitted or received, because the estimation of I-component does not give information about Q-component. Besides, both components are affected by the same fading when the signal is propagated over the channel. In the case of a rotated constellation, a certain rotation angle is applied in the complex plane to a classical signal constellation, such that each component, I-component or Q-component, has enough information by its own to estimate which the transmitted symbol was. The appearance of a rotated constellation is depicted in Fig. 2.13, where the corresponding conventional constellation is also plotted [30] [32]. Two examples are shown, a QPSK (Fig.2.13a) and 16-QAM (Fig 2.13b) constellations.

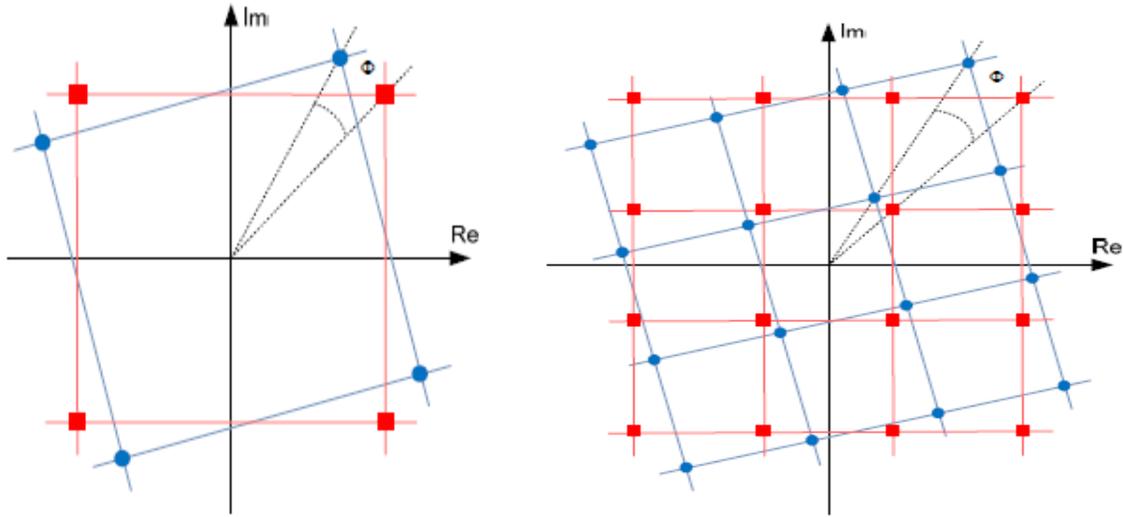


Fig. 2.13: (a) Rotated and classic QPSK constellations. (b) Rotated and classic 16-QAM constellations. The red square points represent the conventional constellation; the blue circles show the rotated constellation [32].

After the rotation, an interleaving process is accomplished only over the Q components. The result will be in order to transmit separately the I-component and Q-component of a constellation point in different carriers as well as in different time slots. Thus, if either I or Q-component is destructed or affected by a deep selective fading of the channel, one of the two components can be used to recover the information. Moreover, the in-phase (I) and quadrature (Q) components of a transmitted symbol are affected by independent fading due to the interleaving process. The technique result is to increase the robustness of the receiver in propagation scenarios with deep fades and/or erasure events. In short, the constellation rotation technique improves the performance of a DVB-T2 receiver in all the fading channels [33].

2.2.5.3 Rotational angle in DVB-T2

The performance gained when using rotated constellations depends on the choice of the rotation angle as earlier illustrated in fig. 2.13. The optimum rotation angle depends upon on the chosen modulation and channel type. However, in DVB-T2, a single rotation angle has to be chosen for each constellation size independently of the channel type. The angle values are presented in Table 2.2 below. Even though those angles are only optimum for a particular channel type, they always present a performance improvement respect to non-rotated constellations in fading

channels with or without erasures. The angle values given in Table 2.2 are a good compromise for all feasible channels in DVB-T2 [34].

Table 2.2: Rotation angles in DVB-T2

Modulation	Rotation angle (Φ) (degree)
QPSK	29.0
16-QAM	16.8
64-QAM	8.6
256-QAM	atan (1/16)

2.2.5.4 Carrier-to-Noise Ratio (C/N)

The C/N characterises the robustness of transmission systems with regard to noise and interference. As such it is used to determine the signal level required to receive a viable signal in noise and interference limited channels as shown in Figure 2.14.

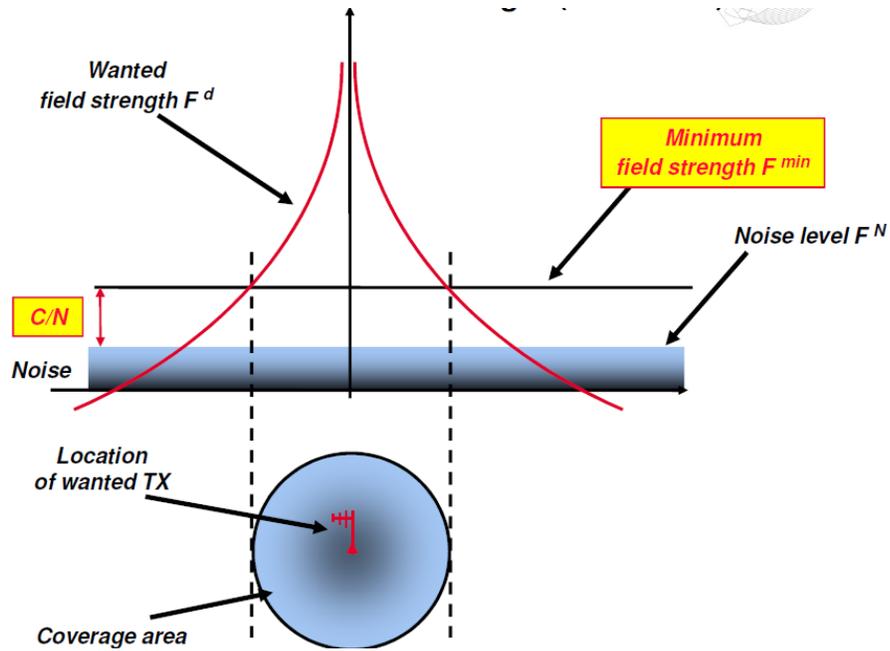


Figure 2.14: Coverage area of the transmitter, C/N and Minimum field strength [35]

Wanted field strength, (F^d) must be greater than minimum field strength (F^{\min})

$$(F^{\min} = F^N + C/N), \quad (2.1)$$

Where;

$$F^d > F^{\min} \quad (2.2)$$

And;

$$F^d > F^N + C/N \quad (2.3)$$

Subsequently, the determination of the C/N is of fundamental importance to network planning. It is important to note that the C/N ratios derived in equation 2.3, are clearly understood to describe the average behaviour of receivers which can be used for frequency network planning. They are not intended to describe minimum receiver requirements in the sense of a specification. The full methodology for determining the C/N of a given mode and receiving environment is described below [35].

Methodology for the derivation of the C/N

The following main steps are necessary when determining the C/N to be used for digital television planning:

Step 1: Identify the target receive environment to determine the reception channel. This means identifying whether the network is directed at fixed rooftop reception, portable indoor, portable outdoor or mobile reception, and for example, will lead to determining whether the C/N for a Ricean or Rayleigh channel is most appropriate.

Step 2: Choose the DVB-T2 transmission mode from Table 2.1. This step usually involves an iterative process where the requirements of capacity, coverage and cost are traded off or optimized. When a DVB-T2 modulation mode is chosen, the simulation based C/N for a Gaussian channel (C/N Gauss-raw) can be found in Table 2.3 and used as the base value for the proposed method [35].

Table 2.3: C/N QEF Valid for DVB-T2 PP2 32k Normal BW GI 1/8 [22]

Constellation	Code Rate	Gaussian Raw Values (Table 2.9)	C/N Gauss	C/N Rice	C/N Rayleigh (static)	0 dB echo channel @ 90% GI
QPSK	1/2	1.0	3.5	3.7	4.5	5.2
QPSK	3/5	2.2	4.7	4.9	6.0	6.8
QPSK	2/3	3.1	5.6	5.9	7.4	8.4
QPSK	3/4	4.1	6.6	6.9	8.7	9.8
QPSK	4/5	4.7	7.2	7.5	9.6	10.9
QPSK	5/6	5.2	7.7	8.1	10.4	12.0
16-QAM	1/2	6.2	8.7	8.9	10.2	10.9
16-QAM	3/5	7.6	10.1	10.3	11.8	12.7
16-QAM	2/3	8.9	11.4	11.6	13.3	14.4
16-QAM	3/4	10.0	12.5	12.9	15.0	16.3
16-QAM	4/5	10.8	13.3	13.8	16.2	17.8
16-QAM	5/6	11.3	13.9	14.4	17.0	19.0
64-QAM	1/2	10.5	13.0	13.3	15.1	16.0
64-QAM	3/5	12.3	14.9	15.2	16.9	18.0
64-QAM	2/3	13.6	16.2	16.5	18.3	19.7
64-QAM	3/4	15.1	17.7	18.0	20.4	22.0
64-QAM	4/5	16.1	18.8	19.3	22.0	24.0
64-QAM	5/6	16.7	19.4	19.8	23.0	25.5
256-QAM	1/2	14.4	17.0	17.4	19.5	20.6
256-QAM	3/5	16.7	19.4	19.6	21.7	23.1
256-QAM	2/3	18.1	20.9	21.2	23.3	25.2
256-QAM	3/4	20.0	22.9	23.2	25.9	28.0
256-QAM	4/5	21.3	24.48	24.8	28.0	30.9
256-QAM	5/6	22.0	25.2	25.6	29.5	33.6

2.3 Multiple Frequency Networks

In the MFN, several transmitters are allocated with frequency each and operate independently from each other. MFN transmitters are standalone transmitters and can run independent channels from each other. For example, three different broadcast frequencies are occupied, each having a spectral bandwidth of 8 MHz. Therefore, the MFN results in a total spectrum consumption of 24 MHz as illustrated in Figure 2.15.

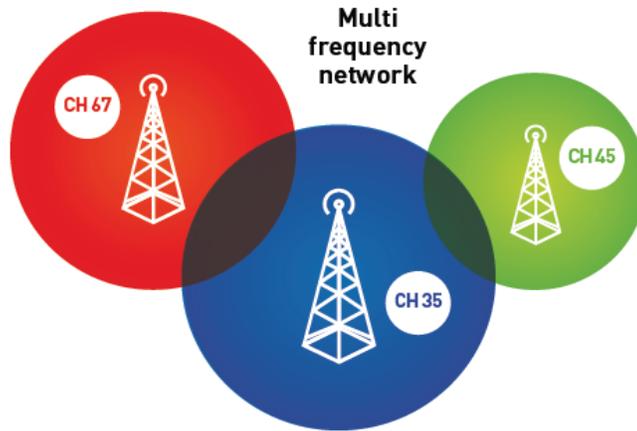


Figure 2.15: Multiple Frequency Network topology [24]

2.4 Single frequency Networks

A Single Frequency Network (SFN) is a broadcast transmitter network consisting of transmitters with overlapping coverage areas that transmit the same programs with same frequency channel at the same time. In a single frequency network all the individual transmitters are exactly time synchronized. Every transmitter must broadcast absolutely identical OFDM symbol at the same time. The DVB-T2 modulation is organised in frames, one frame being composed of sixty-eight (68) OFDM symbols. Four frames constitute one so-called super-frame and two super-frames compose so-called mega-frame (in the mode 2k four super-frames). With regard to different time duration of the symbol OFDM, which depends on the parameters of used modulation and encoding (mode i.e. number of carriers, code rate, guard interval etc.), the time duration of single frame can be different, too [37].

Time synchronization of the all transmitted packets in the transport stream of the final data multiplex is safeguarded by the time signal one pulse per second (PPS), which is obtained from the GPS system. This signal controls time synchronous insertion of the special packet Mega frame Initialization Packet (MIP) into the transport stream at the beginning of every mega-frame. Transport stream MPEG- 2, generated, e.g. in the playout center (TV studio), can be carried to the individual transmitters by the diverse distribution networks (via satellite, microwave line, optical fibre, ATM networks) with different time delays. Therefore the time synchronization by the GPS signal is implemented again in each of transmitters. Consequently, at every DVB-T transmitter broadcasts identical OFDM symbols at exactly the same time. Consequently, the same signal can

arrive at a receiver antenna from different SFN transmitters, each with its own delay, which is related to the distance between receiver and transmitter [38].

There are inherent defects associated with SFN when it is deployed. SFN transmission can be considered as a severe form of multipath propagation, where the receiver receives multiple echoes of the same signal from different transmitters, as well as constructive or destructive interference among these echoes, known as self-interference, which may result in fading. Especially in wideband communication and high data rate digital broadcasting, the fading is more severe, in this case, it is known frequency selective fading, and the time spreading of the echoes may result in inter-symbol interference (ISI). In practice, the effects of fading and ISI can be avoided by means of employing diversity schemes and equalization filters.

The receiver can deal with this effect in the same way as it deals with multipath propagation: the signals arriving from distant transmitters are considered as echoes from the signal arriving from the nearby transmitter. In conventional analog transmission schemes (as PAL television) multipath reception results in ghost images, i.e. positive and negative. So SFNs were traditionally not possible in analogue television transmission. However, since OFDM systems with guard intervals are inherently capable of handling multipath, SFNs have become practical in digital television broadcasting and improve the efficiency of spectrum usage considerably, the SFN-feature is an important advantage of OFDM systems over analog and single carrier digital systems [35] [39].

Compared with conventional analogue broadcasting networks, there is an inherent gain yielding better coverage and frequency economy in SFN because of transmitter diversity. Thus, low outage probability can result from modest transmit power. In contrast with a traditional multi-frequency network (MFN) as in Figure 2.15, all transmitters in a SFN are fed by an identical and synchronised signal through Global Position System (GPS), which is transmitted by occupying the same frequency block, as depicted in Figure 2.16.

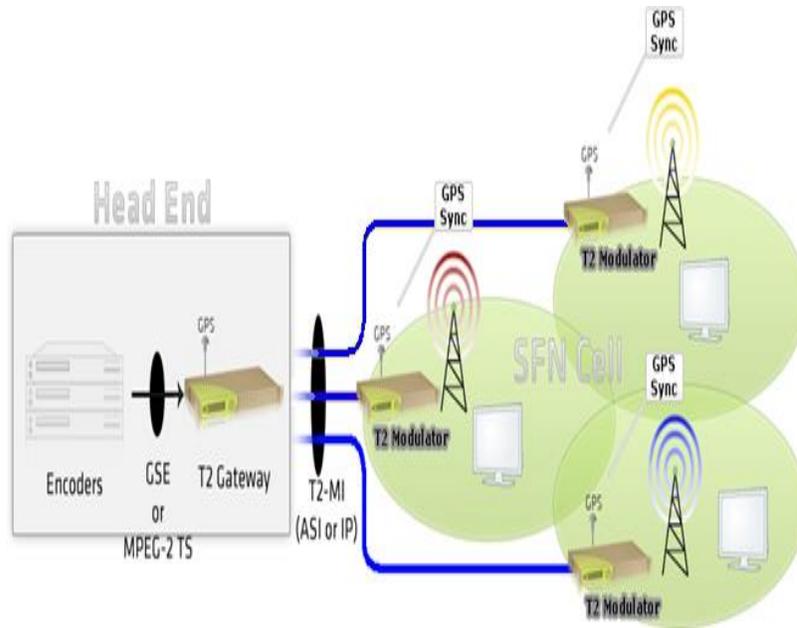


Figure 2.16: Single frequency Network Topology [24]

The aim of SFN transmission is to efficiently utilise the radio spectrum in comparison to traditional MFN transmission [31] [32]. The transmitted signals will arrive at the receiving antenna through two or more paths, which include multipath from atmospheric ducting, ionospheric reflection and refraction, as well as reflection from water bodies and terrestrial objects such as mountains and buildings. During the simulcast transmission, signals are delayed according to different distances between the transmitter (TX) and the receiver (RX). At the receiver side, signals are added and appear to be the result of a transmission over a single time-dispersive channel as shown in Figure 2.17.

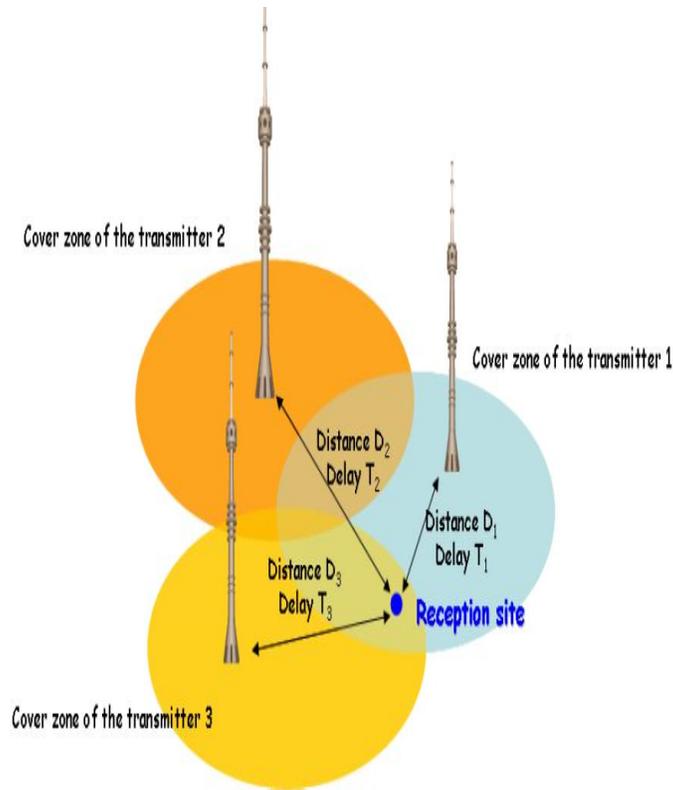


Figure 2.17: Reception site receiving multipath signals [24]

DVB-T2 allows single frequency networks operate within a given geographical area, where more than two transmitters carrying the same data can operate on the same frequency. In such a case the signals from each transmitter in the SFN need to be accurately time-aligned, which is done with synchronization information in the T2MI stream added by the T2 Gateway at the headend. The DVB-T2 standard also includes Multiple Input Single Output (MISO) based on Alamouti coding mode. The key benefit coming from the MISO SFN is observed by less degradation in terms of minimum receiver input power, while a degradation of several dB is measured in SISO-SFN (caused by the fading effects that are leading to the spectral cancellations) [31].

The T2 Gateway aims at encapsulating the incoming MPEG-2 TS into baseband frames, inserting synchronization information for SFN broadcasting, controlling modulators configuration, scheduling the M-PLP broadcasting as well as the TFS allocation. The T2 Modulators receive configuration from the T2 Gateway, perform the channel encoding by adding the forward error correction information, build the T2 frames, and modulate the signal prior to transmit it. A DVB-T amplifier could be used to broadcast DVB-T2 by upgrading its DVB-T modulator to a DVB-T2

one. DVB-T2 standard has defined a new protocol interface the T2-MI (T2-Modulator Interface) to communicate between the T2 Gateway and the Modulators. The T2-MI packets carry the data encapsulated into black and burst Frames and provide for synchronization information when broadcasting over SFN and include all the signaling information for the transmission. All the PLP, TFS, SFN features are scheduled from the T2 Gateway and described within specific T2-MI packets [31].

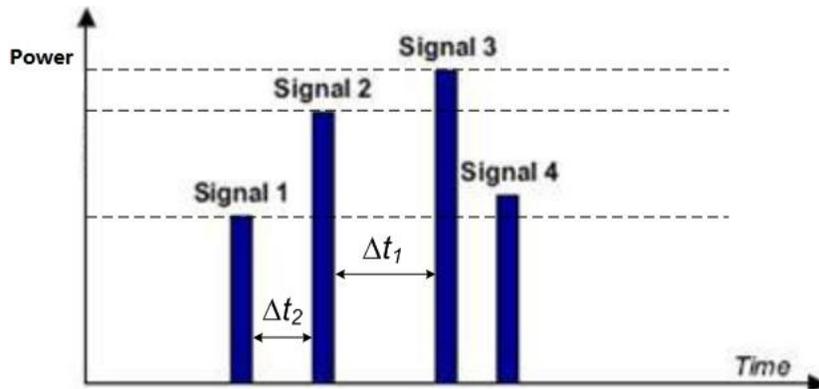


Figure 2.18: Multipath delay at the Receiver Site [24]

In SFN, all the individual transmitters must be synchronised with one another. The programme distribution is injected from the playout centre or the headend in which the MPEG-2 multiplexer is located, e.g. via satellite, optical fibre or microwave link. It is clear that MPEG-2 transport streams are subjected to the different feed line delays due to different path lengths as shown in Figure 2.18. It is necessary that in each DVB-T2 modulator in an SFN network the same transport stream packets are processed into COFDM symbols. Every modulator must perform every operating step completely and in synchronism with all the other modulators in the network. The same packets, same bits and same bytes must be processed at the same time. Every DVB-T2 transmitter site must broadcast absolutely identical COFDM symbols at exactly the same time.

As such, SFN transmitters are synchronised through the GPS with one pulse per second (1PPS) so that transmitters broadcast at the same time in order to avoid bad echoes interferences. Also, 10MHz frequency is used as a reference for transmitters to propagate the same subcarriers [29].

Single Frequency Network is better approach in terms of frequency and power efficiency than MFN. On the one hand, the fact that all transmitters employ the same frequency band leads to an efficient use of the available bandwidth and mitigates the frequency planning process. On the other

hand, the network gain, i.e. the diversity gain provided by the SFN architecture enriches the overall performance of the broadcasting network, increasing coverage over bigger geographical areas, reducing the power and saving frequency spectrum as compared with analogue networks [37] [38]. All SFN transmitters broadcast, synchronously, the same symbol at the same frequency band, and some adverse effects must be overcome. SFN nature contributes to artificial multipath propagation from different transmission sources to the receiver. Consequently, signals or echoes at the receiver side are combined and also, depending on their propagation delays, SFN can induce self-interference and intersymbol interference (ISI) [38].

Thus, the network-generated self-interference can be preserved low enough or eliminated by a careful choice of different system parameters. The availability of approaches to be applied during the planning, deployment or improvement stages of SFN is of paramount importance for network drivers. The optimisation of different network parameters such as transmitters' static delays or transmitter power can lead to the reduction of self-interference, improving the effective coverage over the area. For instance, introducing appropriate static delays at the transmitters makes it possible to act on the pre and post-echoes at the receiver side and the same idea relies on transmitter power reduction, leading to self-interference reduction in certain directions. Furthermore, the optimization of the number of transmitters, their locations and associated powers can contribute to efficient management of SFN [39] [40].

In the latest years, heuristic optimization algorithms such as the particle swarm optimization (PSO), simulated annealing (SA) and genetic algorithms (GA), have been successfully applied in many scientific areas, including the optimization of mobile wireless systems apart from SFN in digital television broadcasting. Based on recent literature, these algorithms have been successfully applied to optimize the locations, transmission powers and static delays of the transmitters within the network. For instance, in the optimization of transmitter powers and locations along with antenna heights in SFN is formulated as a discrete optimisation problem solved by SA. In the SA and GA algorithms are devoted to optimize the location as well as number of transmitters, considering a discrete set of potential prospects and trying to maximize the percentage of covered traffic with the least economical cost, i.e. reducing the number of transmitters as far as possible. Furthermore, GA are applied in the networks to optimize the number of transmitters along with its

power. The reduction of self-interference in SFN is fulfilled in using SA and GA to optimize the internal static delays applied to transmitters [40].

2.5 Mixed MFN - SFN

The SFN approach can also be mixed with the MFN concept. This may be confronted in the following cases: Within an MFN using high power main stations, if one such station does not render complete coverage, lower power relay stations (gap-fillers or repeaters) may complete the coverage using the same frequency as the related main station e.g. Lusaka and Chilanga transmitters. This configuration could also be called hybrid MFN - SFN. Another case may consist of using an MFN structure for transmitting a national multiplex and an SFN structure for transmitting a regional multiplex. In other cases, this type of mixed network scenario could arise from different approaches in adjacent countries (e.g. an MFN approach in one country and an SFN one in the other).

2.6 Guard Interval

In order to overcome the inter-symbol interference problem in Single Frequency Networks, part of the symbol is copied from the beginning of the symbol to the end, increasing its duration by a certain amount of time called the guard interval. This cyclic prolongation of the original symbol is shown in Figure 2.19. The guard interval is denoted by delta (Δ).

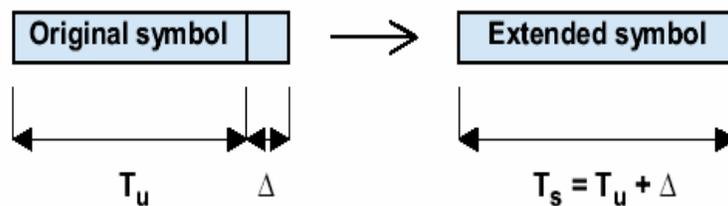


Figure 2.19: Guard interval [2]

The new increased symbol duration is denoted by T_s and the original symbol duration is often called useful symbol duration, T_u . The duration of the FFT-window during which the symbol is evaluated is kept at the original value, T_u . The orthogonal relationship is kept with the original symbol duration, T_u not the extended, T_s .

Signals arriving within guard interval are considered as constructive and signals arriving after the guard interval are destructive interferers as illustrated in Figure 2.20.

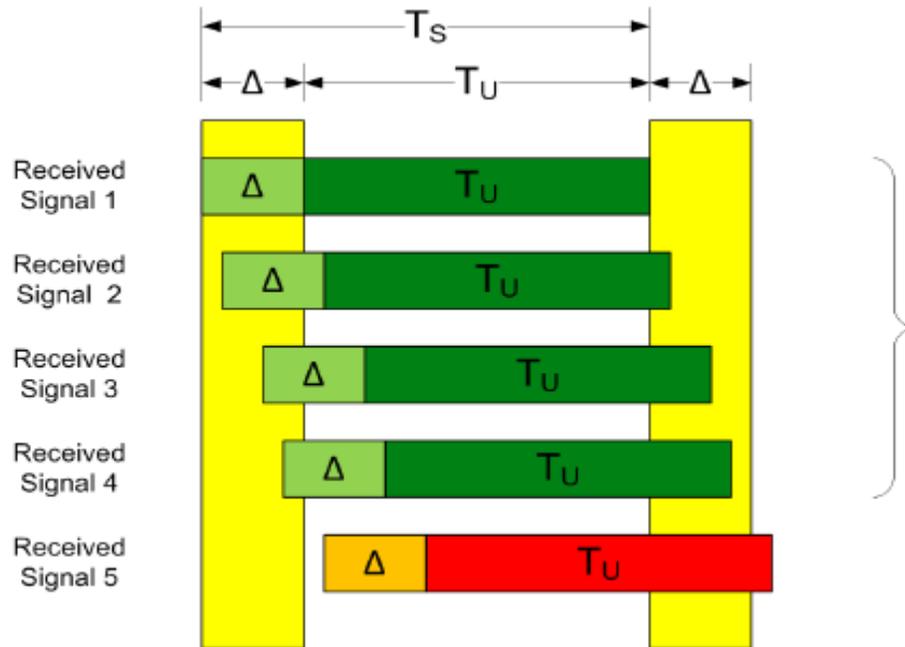


Figure 2.20: Received signal 5 destructive interferer [2]

Received signal 5 will cause intersymbol interference due the fact that the signal will fall beyond the guard interval as shown in Figure 2.20.

The exact choice of frame length will depend on the selections of the following key parameters, but not limited to:

- i. FFT size.
- ii. Guard interval value.
- iii. The use of extended-carrier mode.
- iv. The combinations of different types of PLPs.

For instance and in order to appreciate the indicated key parameters deployed in digital television transmission, a television channel of 8 MHz frequency band permits in a specific setup of 8k mode COFDM modulation with sub-carrier m-state quadrature amplitude modulation (64-QAM) to reach a bit rate (R_b) of data stream $S_b(t)$ $R_b \approx 22$ Mbit/s. The time interval (T_b) of one bit = $1/R_b \approx 45$ ns. The number n of orthogonal sub-carrier waves in DVB-T2 standard is $n = 2048$ (for 2k mode), $n = 8192$ (for 8k mode), eventually for DVB-H also $n = 3408$ (for 4k mode). For the actual transmission of the information data, not all the sub-carriers are employed in 2k mode, the number of active sub-carriers is $n = 1075$ and in 8k mode, there are $n = 6817$ active sub-carriers [31] [32].

The remaining sub-carrier waves are applied as pilot signals, and some of them carry information about the parameters of the modulation used. The frequency gap, ΔF , between sub-carrier frequencies must conform to the bandwidth Bk of the allotted frequency channel (for video broadcasting 8, 7, 6 MHz) and represents, in fact, the symbol rate R_s of OFDM modulation. For 8 MHz bandwidth channels, used in frequency raster of terrestrial transmission as well as cable distribution e.g. in the Czech Republic (the exact value is 7.61 MHz), the spacing of sub-carrier frequencies ΔF , which also represents the symbol rate R_s , can be written as in equation 2.1;

$$\begin{aligned}\Delta F &= R_s & 2.1 \\ &= Bk/n \\ &= 7.61 \cdot 10^6/6817 \\ &= 1.116 \text{ kHz (1)}\end{aligned}$$

The corresponding time extended symbol T_s as shown in equation 2.2;

$$\begin{aligned}T_s &= R_s^{-1} & 2.2 \\ &= (1.116 \times 10^3)^{-1} \\ &= 896 \text{ } \mu\text{s. (2)}\end{aligned}$$

This time is then further extended by the so-called guard interval, T_G , which is often defined as a part (kT) of symbol time as shown in equation 2.4;

$$\begin{aligned}kT &= T_G/T_s & 2.3 \\ &= 1/4, 1/8, 1/16, 1/32.\end{aligned}$$

No useful information is transmitted in the guard interval, T_G . It is employed to eliminate reception of delayed signals and thus influences the possible choice of transmitter distances in the SFN. For instance, in 8k mode transmitted in a channel of 8 MHz bandwidth, the longest guard interval of

$$\begin{aligned}T_G &= kT \cdot T_s & 2.4 \\ &= 1/4 \cdot T_s \\ &= 896/4 \text{ } \mu\text{s} \\ &= 224 \text{ } \mu\text{s}\end{aligned}$$

So the guard interval of 224 μ s can be achieved as shown in equation 2.4. The time properties within the OFDM signal conforming to different mode/ bandwidth settings for the longest time interval with $kT = 1/4$, calculated based on the considerations above, are listed in Table 2.4.

Table 2.4: Time properties within the COFDM signal for modes 2k and 8k and $kT = 1/4$ [32]

Channel bandwidth [MHz]	Mode 2k ($k_T = 1/4$)			Mode 8k ($k_T = 1/4$)		
	$T_S[\mu s]$	$T_G[\mu s]$	$T_S+T_G[\mu s]$	$T_S[\mu s]$	$T_G[\mu s]$	$T_S+T_G[\mu s]$
8	224	56	280	896	224	1120
7	256	64	320	1024	256	1280
6	298	75	373	1197	296	1493

In Table 2.4, the total lengths of extended symbols $TN = T_S+T_G[\mu s]$ can be noted. Based on the values, it can be showed that the bit rate R_b of the input bit stream that the OFDM encoder can process in the respective modes. For instance, if a usual internal modulation of the orthogonal sub-carrier waves 64-QAM is used, where one modulation symbol holds $m = 6$ bits of the input serial stream, It can be written for a 8 MHz bandwidth channel in 8k mode and the guard interval with factor $kT = 1/4$ as seen from Table 2.5

$$\begin{aligned}
 R_b &= (T_S + T_G)^{-1} \cdot n \cdot m \\
 &= (1120 \times 10^{-6})^{-1} \times 6817 \times 6 \\
 &\cong 36 \text{ Mbit/s. (4)}
 \end{aligned}$$

The value expresses the maximum bit rate that can be processed and allows even suitably compressed (MPEG-4, MPEG-4 AVC) digital television signals in high definition HDTV to be broadcast in the future. The truly usable bit rate R_{bn} (Net Data Rate) is lower, as the protective data stream of the inner and outer error protection codes called forward error correction one (FEC1) and forward error correction two (FEC2) is added to the usable information data stream[33] [34]. The FEC1 and FEC2 represent a redundant, yet purposeful extension of the data stream. As the outer block (symbol) error protection code FEC1, DVB-T uses the Reed-Solomon code RS 204,188, which adds 16 parity bytes to the 188 bytes transport packets and permits a correction of up to 8 erroneous bytes. The inner code FEC2, a bit-based protective code, is a convolutional code with variable code rates $KR = 1/2, 2/3, 3/4, 5/6$ and $7/8$. As a result, the usable bit rate R_{bn} is lowered to the value

$$R_{bn} = 188/204 \cdot KR \cdot R_b. \quad 2.5$$

In the extreme case of the highest quality protection ($KR = 1/2$), the usable bit rate R_{bn} goes down to 46 % of the original value R_b and, according to equation (4), to the value

$$R_{bn} = 0.46 \times 36 \times 10^6$$

$\cong 26.5$ Mbit/s.

For the very often used code rate $KR = 2/3$, the decrease is circa 61.4 %, and thus $R_{bn} = 22.3$ Mbit/s. This bit rate can hold a data multiplex of roughly 4 to 5 compressed program stream (MPEG-2) of television programs having standard PAL quality, several stereo sound radio programs and other services e.g. Teletext, MHP1 (Multimedia Home Platform with local interactivity), etc. The component program streams do not usually have constant bit rates assigned. Statistical multiplexing is employed instead, where the instantaneous bit rate is assigned as higher for the programs with richer information content (dynamically demanding video sequences containing high spatial frequencies of luminance as well as chrominance distribution, sport transmission, for instance) at the expense of reducing bit rates of other streams. It is also obvious in *Tab. 1* that the longest guard interval can be obtained at channel bandwidth 8 MHz used in television broadcasting in 8k mode; $T_G = 224 \mu\text{s}$.

The theoretically largest diameter of the region with a working single frequency network and accordingly, the maximum possible distance between the transmitters working in this network, provided the signals anywhere in the monitored area reach the over-threshold level, can be described by a formula expressing the distance of an air propagated electromagnetic wave delayed by T_G (in this particular case)

$$\begin{aligned} \text{Maximum distance between transmitters, } D_{\max} &\leq C \cdot T_G \\ &= 3 \times 10^8 \times 224^{-6} \text{ km} \\ &\cong 67 \text{ km (6)} \end{aligned}$$

Where C = speed of light and T_G = Guard interval

In 2k mode, this distance would be four times shorter due to four times shorter guard interval (*see Tab. 1*). However, it is worth noting, that the 2k mode is more suitable for mobile reception as the sub-carrier spacing is four times wider and consequently the signal is much more robust to Doppler shift (the receiver can move faster, yet ensuring error-free reception).

2.7 Choice of Fast Fourier Transform(FFT) size for SFN network

Nominal FFT size is used for a particular mode, equal to the active symbol period, T_s , expressed in cycles of the elementary period T . For high-bit-rate service and fixed rooftop antennas, 32k mode is recommended and for mobile reception, smaller FFT size should be used. Operation in L-Band

(about 1.5 GHz, BW 1.7MHz), 1k mode is usually recommended. Increased FFT size will give a greater delay tolerance for the same fractional guard interval, allowing larger SFN to be constructed. Alternatively, a larger FFT size allows the same delay tolerance to be achieved with a smaller overhead due to the guard interval. A larger FFT size entails a longer symbol duration, which means that the guard interval fraction is smaller for a given guard interval duration in time. Additionally, the larger FFT sizes have a greater vulnerability to fast time-varying channels, i.e. have lower Doppler performance.

For a given FFT size, constellation and code-rate, the Doppler performance is roughly proportional to RF bandwidth (halving the bandwidth will halve the carrier spacing resulting in half the Doppler performance) and inversely proportional to the RF frequency [16].

The extended-carrier option has the obvious benefit of increasing the data capacity. DVB-T has made it possible to build SFN networks but, DVB-T2 offers a wide range of possible guard intervals in order to support a range of broadcasters needs. The longest guard interval lasts only 224 μ s and that has limited the size of the SFN network in DVB-T. In DVB-T2 16K and 32K makes it possible to have much longer guard interval which makes it possible to build very large SFN networks as illustrated in Table 2.5. In summary, DVB-T allows a maximum transmitter separation distance of 67.2 km while DVB-T2 allows 159.6 km.

Table 2.5: Fast Fourier Transform and Guard Interval parameters [25]

FFT size	Guard-interval fraction						
	1/128	1/32	1/16	19/256	1/8	19/128	1/4
32K	28	112	224	266	448	532	N/A
16K	14	56	112	133	224	266	448
8K	7	28	56	66.5	112	133	224
4K	N/A	14	28	N/A	56	N/A	112
2K	N/A	7	14	N/A	28	N/A	56
1K	N/A	N/A	7	N/A	14	N/A	28

2.8 Model for the Terrestrial Receivers

The SFN transmission can be considered as a severe form of multipath propagation, so all the signals arriving at each receiving location from each transmitter must be properly handled in the OFDM receivers to maintain the spectrum efficiency. Basically, the receiver block synchronizes and combines all the echoes to obtain the useful and interfering components at every point of the meshed area, i.e. the aggregate C and I , respectively. In this work, based on the time instant, t , in

which each signal arrives at every receiving location, the receiver mask in (1) weighs up the completely or partially contribution of each signal to the C and I components as illustrated in equation 2.6.

$$\omega_n = \begin{cases} ((T_u - t) / T_u)^2 & \text{if } (T_g - T_p) < t \leq 0 \\ 1 & \text{if } 0 < t \leq T_g \\ ((T_u + T_g - t) / T_u)^2 & \text{if } T_g < t \leq T_p \\ 0 & \text{otherwise} \end{cases} \quad 2.6$$

in which the useful symbol length, T_u , the guard interval, T_g , and the time limit during which the echoes can positively contribute to the suitable recovery of the information sent, $T_p = 7T_u/24$, depend on the DVB-T mode considered [3].

2.9 Gapfiller (Fill-in) transmitters

Gapfillers are low power co-channel mini-transmitters with high gain antennas for receiving the signals from the main station, boost and retransmit the signal to fill in the challenged coverage gaps. Gapfillers are often used for coverage of small areas with poor reception from a main transmitter. The radiated power of a fill-in transmitter is low and often have a directional antenna to service a specific area. Gapfiller transmitter has limited interference potential to other TV transmitters. For this reason and because of the coverage area, the transmitter is, in general, shielded from other transmitters making frequency reuse distances relatively small. Gapfiller transmitters are fed off-air from a main transmitter from another to provide small SFN-MFN network. In order to achieve sufficient selectivity the received signal is down-converted to IF and reconverted to the required transmission frequency. The transmission frequency can be different from the received frequency or the same. In the latter case the gapfiller transmitter operates as SFN with the main transmitter [1]. Figure 2.21 shows the principle of a fill-in station in SFN mode.

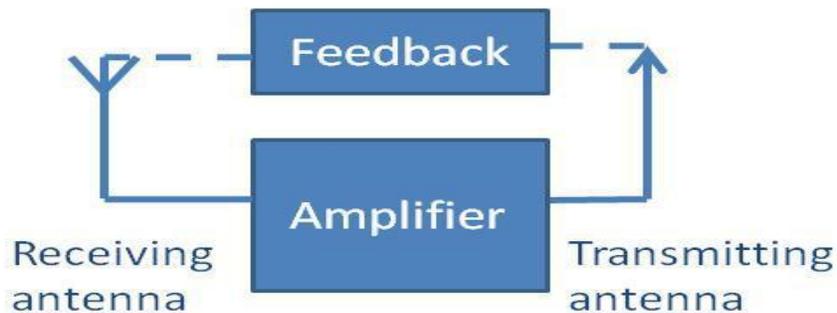


Figure 2.21: Principle diagram of a fill-in station in SFN mode [26]

To prevent oscillation, the gain of the fill-in transmitting equipment must be lower than the measured feedback. Measured isolation values in Europe range from about 60 to 110 dBu. In general a safety margin of 10 dBu is applied to the isolation value in order to allow for time variations. Modern gapfiller transmitter equipment with advanced echo cancellation allows amplification of 10 to 15 dB above the isolation value [26].

A calculation example of the allowed radiated power for two cases, a gapfiller transmitter with and without echo cancellation, is given in Table 2.6.

Table 2.6: Showing calculation example fill-in transmitter power [26]

Element	Fill-in transmitter without echo cancelling	Fill-in transmitter with echo cancelling
Measured input signal (P_i)	-75 dBW	-75 dBW
Measured isolation minus 10 dB safety margin (I)	65 dB	65 dB
Gain margin (G_m)	0 dB	10 dB
Maximum gain ($I + G_m$)	65 dB	75 dB
Output power ($P_o = P_i + I + G_m$)	-10 dBW	-0 dBW
Transmitting antenna gain minus cable loss (G_t)	10 dB	10 dB
Allowed radiated power ($ERP = P_o + G_t$)	0 dBW	10 dBW

The isolation value can be improved by:

- i. Larger separation between receiving and transmitting antenna;
- ii. Increased receiving and transmitting antenna directivity;
- iii. Use of orthogonal polarization between input and output signal.

At VHF, the isolation between input and output signal is lower due to lower antenna directivity and lower free space loss. If the radiated power is not sufficient to cover the area, either a transmitting frequency different from the receiving frequency should be used (the gapfiller transmitter operates as MFN) if available, or the gapfiller transmitter should be fed by microwave link, satellite or cable. In the latter case, the gapfiller transmitter should be equipped with a modulator. Gapfiller transmitters are a cost effective and frequency efficient way to improve coverage in small and complex areas, provided that a sufficiently strong input signal can be received. An input level above -55 dBu is generally needed to ensure a good quality output signal. These transmitters can operate on the same frequency as the main station in the SFN, but care must be taken to ensure sufficient isolation between input and output signal. The output power depends on isolation value. For that reason measurements and possibly adjustments are needed at each site

and at each frequency before the transmitter becomes operational. Gapfiller transmitters with different receive and transmit frequency, have no technical limitation in radiated power [26].

2.10 Set-Top-Box (STB)

When International Telecommunications Union (ITU) decided to transform analogue to digital terrestrial broadcasting, most of its consumers were using analogue TV sets. Costs and interoperability were identified as key factors influencing digital take up in a number of countries that have implemented. ITU felt that it was unrealistic to expect consumers to replace them immediately with digital TV receivers because digital television set were going to be expensive and unaffordable to consumers. Hence, a set-top-box provided the interim solution.

Currently, a STB is a major interface that convert transmitted digital video signals transmitted through satellite, cable, terrestrial or Internet Protocol Television (IPTV) to the standard that can be displayed on the standard LCD, LED, and analogue TVs. The DVB-receivers for different transmission scheme used are the same except for demodulator. Hence, a single set top box can be used to receive DVB-T, DVB-S and DVB-C signals. There are two concepts for the architecture of the STB; open architecture and interoperable. The STB has a number of independent functional modules that are interconnected consisting of hardware and software associated to intellectual property (IP). Open architecture needs all the intellectual properties used in STB to be governed by the fair reasonable non-discriminatory terms set by recognized international bodies. Interoperable on the other hand means it should have the capability to receive signals from any of the DVB transmission type. The output from the input modules (tuner and demodulator) is MPEG-2 transport stream. The STBs have modem to allow it to send and receive interactive data as shown in Figure 2.22.

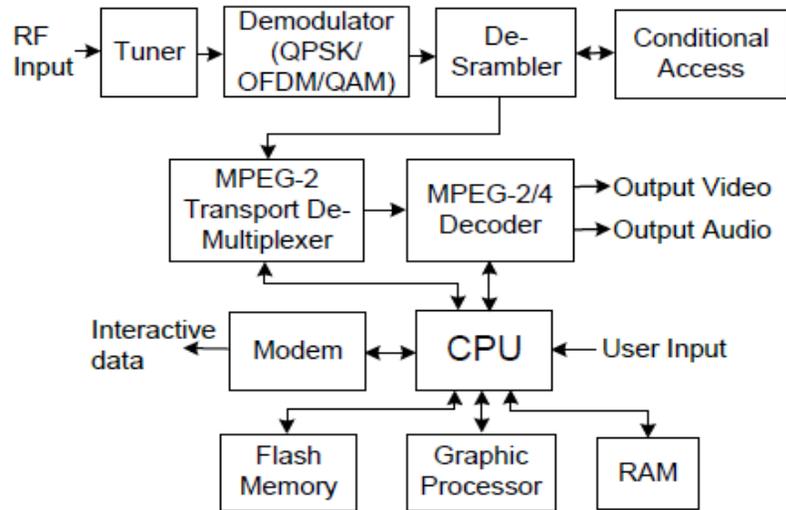


Figure 2.22: STB block diagram [2]

The cost of STB has been an issue for digital migration strategy for terrestrial TV broadcasting in many countries, Zambia inclusive, that needed to be addressed to promote quick digital take-up. Policy and guidelines have been adopted by different countries ranging from providing free set-top-boxes to some households to subsidize or tax relief offer by governments. Having a single STB to receive all terrestrial broadcasting services from different players for free-to-air (FTA) and scrambled services is another way intended to address consumer needs and convenience.

This has remained an area of contention between broadcasters and the regulatory authorities on the minimum mandatory specification of a set-top-box for digital terrestrial broadcasting. Countries with weak economies without high definition (HD) TV broadcasting have interest in standard definition (SD) whereas countries with high penetration in pay TV their concern was on the free-to-air (FTA) offering capabilities. Hence, in countries like Malaysia and New Zealand, HD was considered as mandatory requirement while SD was a backward compatible requirement for digital terrestrial receiver for free-to-air reception or unencrypted services. What is significant is to define required and optional categories specifications [20].

2.11 DTT Implementation in Zambia

Zambia is a member of ITU and in a process to transform analogue to digital terrestrial television broadcasting platform. This will be in conformity with the provisions of the Geneva 2006 (GE06) Digital TV Broadcasting plan. Many countries in Europe and Western World have migrated to

terrestrial digital TV transmission and consequently, towards plan to end analogue broadcasting as per ITU resolutions. The migration from analogue to digital broadcast systems is a most significant drift in Zambian television broadcasting. Digital Terrestrial Television (DTT) is a modern and advanced technology, which employs digital techniques, rather than analogue, for the broadcasting of television services. Programme content flexibility and specific inherent technical advantages put DTT in a significant position to supersede current analogue systems in Zambia. International standards are in place for DTT across the world, and these are undergoing refinement as the base of understanding and experience with the technology continue to develop.

The Government’s objective is countrywide digital television coverage of at least seventy-three (73) DTT transmission sites to cover the entire Zambia as indicated in Figure 2.23. High power transmitters were planned to be installed along the line of rail, medium power transmitters in provincial centers and low power transmitters in districts across the Zambia.

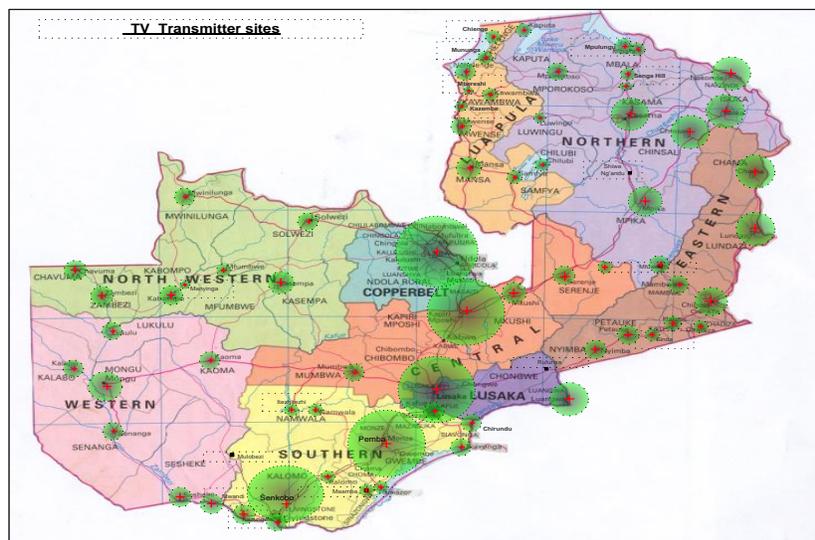


Figure 2.23: Proposed DTT sites in Zambia [18]

National Task Force (NTF) on digital migration was set-up by the Zambian government to make recommendations and generally oversee the national digital migration process. The operations of the task force were managed by a national steering committee which composed of Ministry of Information and Broadcasting Services (MIBS), Zambia Information Communications and Telecommunication Authority (ZICTA), Zambia National Broadcasting Corporation, (ZNBC) and some private media organisations like Muvi TV, Mobi TV and others.

The NTF was tasked by MIBS among other terms of reference to facilitate the creation of independent signal distributor(s), to provide signal distribution guidelines to all licensed

broadcasters and develop clear terms, conditions and tariff framework for infrastructure sharing and fair competition among operators in the broadcast industry. [18]

2.11.1 Digital television policy in Zambia

The DTT migration policy for Zambia was formulated to aim at the following:

- i. Develop digital broadcasting market structure and licensing framework
- ii. Define national technical standards in order to ensure interoperability, economies of scale and safeguarding universal services.
- iii. Provide a framework for content development and regulation in order to promote diversity and create jobs.
- iv. Develop and provide guidelines for the establishment and operation of signal distributors.
- v. Facilitate public consultation, awareness and provide mechanism for consumer protection.
- vi. Provide a timeframe and schedule of digital transition in order to undertake orderly switch over and switch-off [18].

2.11.2 Implementation of DTT policy

The broadcasting environment shall be reviewed to reflect the new realities of digital broadcasting. In order to implement the policy, Government's agencies; IBA and ZICTA shall [18]:

- i. Review the frequency licenses and revoke all analogue frequencies by switch off date and allocate frequencies only to signal distributor(s)
- ii. Develop signal distributor and content service provider regulations
- iii. Review the operations of ZNBC as a public broadcaster in line with the new business model in the digital environment.
- iv. Ensure that the private signal distributors have a minimum 40% of controlling shareholding held by Zambian citizens.
- v. Ensure that content service provider licenses are issued to Zambian citizens or to companies in which a minimum of 75% shares are owned by Zambian citizens

- vi. Ensure that regulators develop and implement tariff and universal access guidelines by switch-on date
- vii. Facilitate the establishment of a public signal distributor and promote through competitive mechanisms, the establishment of private signal distributors
- viii. Require signal distributors to adopt common technologies for devices to be used by the public to access their services
- ix. Ensure that appropriate duties and charges are effected on all imported content.
- x. Ensure local media production houses are promoted to increase local content.

2.11.3 Market Structure and Licensing Framework

The current broadcasting licensing framework shall be transformed into two broad licensing categories namely;

- i. Content service provider(s)
- ii. Signal distributor(s)

The Government policy states that no single entity shall hold both types of licenses at the same time. The licenses shall not be issued to political parties, organizations affiliated to political parties and an individual holding political office.

2.11.3.1 Content Service Provision

Content service provision shall be undertaken by local and foreign content service providers such as ZNBC, MultiChoice, MyTV (Strong Technologies), Revelation, Mobi TV, Muvi TV, CBC Television, Prime TV, Chipata TV, North-West TV, TBN, Parliament TV and France 24. The main role shall be to develop and aggregate broadcasting content and send it for dissemination by the signal distributor. The content service provider will ensure that content is delivered to the national headend and that the content should meet the compression standard (MPEG-4) as prescribed in the policy. Under this category the following licenses shall apply [18]:

i. National Public Content Service Provider

The service will be provided by the Zambia National Broadcasting Corporation, operating commercially, with universal service obligations, and

with public fund support to sustain its universal service obligations. The license shall be for a period of ten years. [18]

ii. Private Commercial Content Service Provider

Private Content Service Providers will be expected to provide a diversity of programming content, contribute to job creation and human resource development. The license shall be for a period of ten years and can be issued as a national, provincial or district license. The license shall have two broad categories:

- a) Free-to-air television broadcasting services capable of being received without a subscription fee payment.
- b) Subscription television broadcasting services to be provided in exchange for the payment of a subscription fee.

2.11.3.2 Private Non-Commercial Content Service Provider

The license shall be issued to a non-profit entity. The license shall be for a period of ten years and can be issued as a National, Provincial or District license [18].

2.11.4 Signal Distribution

Signal distribution shall be undertaken by signal carrier(s). The signal carrier entities shall provide network infrastructure that will receive content after aggregation from broadcasters for multiplexing, signal distribution and provide subscriber management system (SMS). The signal distributors will be required to provide up to five (5) free-to-air program channels for public service and shall be required to establish and operate help desks. Each signal distributor shall be required to develop service level agreements with content service providers which shall be non-discriminatory. Under this category the following licenses shall apply [18]:

2.11.4.1 Public Signal Distributor

The signal distributor shall be required to provide national wide coverage and services to content service providers (licensees) on a non-discriminatory basis in order to provide universal access such as. The public signal distributor shall be formed when Zambia National Broadcasting Corporation will be split into two namely content provider and signal distributor [18].

2.11.4.2 Private Signal Distributor

The signal distributor shall be required to provide national-wide coverage and service to Content Service Providers (licensees) on a competitive and non-discriminatory basis. The private signal distributor shall be established through competitive open tender [18].

2.12 Regulators and Regulations

The regulators shall perform their respective functions in line with their statutory functions as provided for in their constituent Acts:

- 2.12.1 Independent Broadcasting Authority (IBA) shall regulate content and Content Service Providers,
- 2.12.2 Zambia Information and Communications Technology Authority (ZICTA) shall regulate Signal Distributors and frequency allocation,
- 2.12.3 Zambia Environmental Management Agency (ZEMA) shall be responsible for environmental protection and pollution control issues [18].

2.13 Zambia Bureau of Standards STB Specifications Policy

The (ZABS) is the statutory organization established by an Act of parliament. ZABS is responsible for the preparation of national standards through its various technical committees composed of representation from government departments, the industry, academia, regulators, consumer associations and non- governmental organizations [46].

The STB standard and specifications were prepared by the technical committee on terminals and human factors TC 3/16/6 upon which the following organizations were represented: CEC Liquid, Huawei, Mido Engineering Limited, World Bank, Zambia Bureau of Standards, Zambia Information and Communication Technology Authority, Zambia National Broadcasting Corporation, Zamtel and Zesco [46].

In the Zambia Bureau of Standards document, it is stated that the DVB-T2 STB shall be able to demodulate all non-hierarchical modes specified in the ZS EN302 755. The frontend shall work compatibly with any combination of constellation, code rate, transmission mode and guard-interval. The DVB-T2 STB should be able to detect any DVB-T2 mode being used. The DVB-T2 parameters or modes are outlined in Table 2.7.

Table 2.7: DVB T2 Operational Modes [46]

DVB T2 Parameter	Mode / requirement
Constellation	QPSK, 16 QAM, 64 QAM, 256QAM With or without Constellation rotation.
Code Rate	1/2, 3/5, 2/3, 3/4 , 4/5 or 5/6
Guard Interval	19/128, 1/8, 19/256, 1/16, 1/32, 1/128
Pilot Pattern	PP2, PP4, PP6 & PP7
Antenna	SISO & MISO
PAPR	No PAPR & TR-PAPR
Input Mode	Input Mode A & B (Single PLP, Multiple PLP)
Baseband Mode	Normal Mode, High Efficiency Mode
FTT Size	1k, 2k, 4k, 8k normal, 8k extended, 16k normal, 16k extended, 32k normal or 32k extended
Forward Error Correction frame length (FEC)	64 800 bits for normal FECFRAME; 16 200 bits for short FECFRAME
Input Mode	A Single PLP or B Multiple PLP
Input Mode	A Single PLP or B Multiple PLP
Mode Adaptation	Normal Mode (NM), High Efficiency Mode (HEM)
Scrambling of L1 Post Signalling.	Feature shall be supported by the DVB-T2 STB

2.14 Phase 1 Implementation Plan

The Government of Zambia through the MIBS signed a contract with StarTimes Technologies Company Limited of China for the Supply, delivery, installation and commissioning of a National Digital Terrestrial Television Broadcasting System in Zambia for Phase 1 while Phase 2 and Phase 3 were yet to be contracted. Phase 1 includes installation of DTT along the line of rail from Chililabombwe to Livingstone as shown in Table 2.8. Phase 2 will include provincial centers and Phase 3 will carter for all districts across Zambia, respectively.

Table 2.8: Phase 1 DTT stations

No.	Station	Location	Transmitter power
1	Lusaka	15.416843°S; 28.308508°E	5kW
2	Kitwe	12.821805°S; 28.217347°E	5kW
3	Kapiri Mposhi	13.977863°S; 28.684809°E	5kW
4	Pemba	16.474151°S; 27.324352°E	5kW
5	Senkobo	17.598826°S; 25.977781°E	5kW
6	Ndola	13.049540°S; 28.649739°E	0.5kW
7	Chingola	27.854587°S; 12.541955°E	0.5kW
8	Kalomo	17.029905°S; 26.478398°E	0.5kW
9	Kafue	15.849010°S; 28.179236°E	0.5kW
10	Chilanga	15.580898°S; 28.275974°E	0.1kW

2.15 The introduction of DTT coverage system

Zambia's digital TV platform will include both universal service and commercial services while taking both social and environmental factors into consideration. The system would be utilised by media content providers for distribution to the entire country. Mainly, the system would employ the existing infrastructure of Zambia National Broadcasting Corporation like transmitting towers and equipment room in order to lower the initial capital investment.

2.16 Signal distribution network

Fiber network will be used for backbone transmission between the headend and the transmission sites. At the same time, a C-band satellite transmission system will be setup as a backup for the public channels. Furthermore, satellite signal distribution will also be used to provide direct-to-home (DTH) service via Ku band to areas where terrestrial transmission will be difficult to access. Both national and private television stations' programs will be uplinked to the satellite transponder and downlinked to remote areas for retransmission through DTT transmitters and also to other countries or regions to enhance the international transmission ability of the Zambian local programs shown in Figure 2.24.

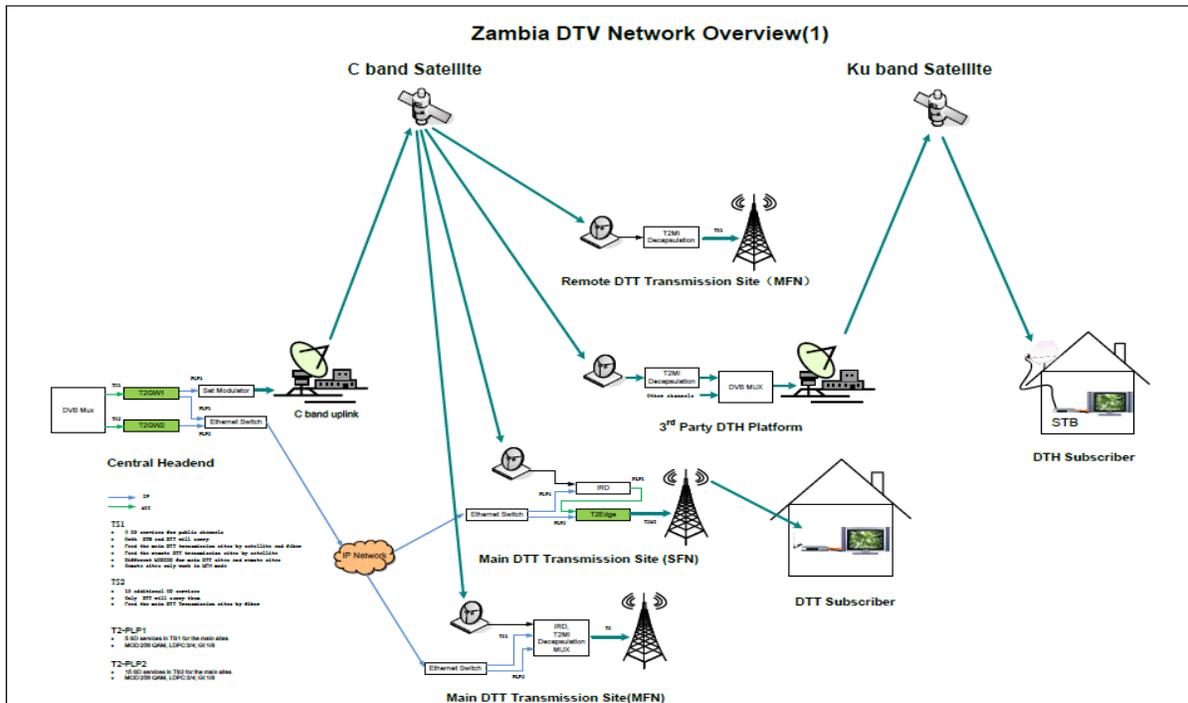


Figure 2.24: Content distribution network

2.16.1 Video and audio encoding

The signal content providers will use advanced MPEG-4 AVC (H.264) compression to encode standard definition (SD) and high definition (HD) programs. The compression structure will maintain high quality in low transmission bitrate. A standard definition program can be compressed to about 2Mbps and high definition programme to about 4-7Mbps, respectively.

The multiplexer will be configured in the system support network-based statistical multiplexing technology, and the encoder will be able to achieve bit rate information real-time feedback for each channel of the encoder in order to accomplish dynamic statistical multiplexing encoding for encoders. In this way, the system will not only save bandwidth, but also achieve higher quality of program encoding.

2.16.2 DTT national headend

The central DTT headend will accomplish digital TV signal reception for monitoring, encoding, multiplexing, scrambling and management control system network. It will be equipped with network monitoring tools and operating management systems for real-time monitoring of the system operational status. The monitoring status will include the input and output video with embedded audio signals, the individual equipment and output transport streams, power supply

condition for each station, security of the whole system and the remote maintenance of equipment. In summary, national DTT center will be responsible for the unified management of operation and maintenance of the whole system. Figure 2.25 shows the monitoring system of the National Headend.



Figure 2.25: National DTT management center

2.16.3 Remote monitoring system

The remote monitoring system will be in charge of monitoring and maintenance of the operation status of the transmitting stations. In case of any technical fault, it will deliver alarm messages to help maintenance personnel react timely and solve the problem. Thus the system will be automated to provide the status of the transmission system status, for example, loss of signal, loss of electric power supply, fire, high room temperatures, fuel in the electric generator and other technical parameters.

2.16.4 Content integration platform

The platform will be processing program contents that the system needs transmit, and convert them into a standard format so that they can be processed and transmitted in the DTT system. The DTT center will have the capacity to encode 20 standard and 1 high definition channels.

2.16.5 The program composition

The programs transmitted in the Zambia DTT will include programmes of national and private television channels and foreign TV programmes. The transmission of Zambia's local program to the DTT headend should either be fiber network, microwave link or via satellite. The format of standard definition TV shall be Serial Digital Interface (SDI) and that of high definition TV shall be High Definition - Serial Digital Interface (HD-SDI).

2.16.6 Electronic Program Guide (EPG)

Electronic Program Guide (EPG) enables easy and quick selection of programs with a very friendly interface for digital TV subscribers. By using it, the subscribers will be able to know the content and future programme schedules. It will also help customers set parent lock and favorite channels.

2.17 Summary

In concluding, the chapter discussed how ITU regions have adopted different digital broadcasting standards. Despite the ITU setting the analogue switch off (ASO) of 15th June 2015 for Region 1, the implementation process has differed from country to country depending on the ASO goals and market value of the project. This chapter, also, looked at the technical features and architecture of the adopted DVB-T2 standard and the implementation plan for Zambia. It further discussed in details digital modulation standard using the Coded Orthogonal Frequency Division Multiplexing, the choice of rotated constellation, Single and Multiple Frequency Networks, carrier-to-signal noise ratio (C/N), guard interval importance in the DVB-T2 reception and also the allocation of UHF band. The chapter looked at the approved technical specifications for the Set Top Box (STB) as a major interface unit that convert transmitted digital video signals to analogue standard that can be displayed on the standard analogue television sets.

The chapter discussed the details of DTT implementation plan in Zambia and the objective of the Government to implement both the ITU and SADC resolutions. The Chapter also heightened the DTT policy and its action areas, market structure, licensing framework and the relevance of various regulators in the digital era. Further, the chapter, further, discussed the STB technical specifications as per Zambia Bureau of Standards (ZABS) recommendations.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

The research employs qualitative methodologies in form of simulation and signal field strength measurement analysis in order to reveal the quality of reception and the extent of digital television footprint in Zambia. The chapter evaluates the optimal application of Single frequency Network and Multiple Frequency Network, examine the footprint for full coverage of DTT in Zambia and determine the signal field strength (SFS) in flat and complex areas. The triangulation and combination of methodological design of the DTT implementation network are also assessed through software management tools. In terms of the data collection used, the chapter will analyse actual parameters for each transmitter and system network used to transmit digital television, and also, used the actual parameters to generate coverage map prediction of Single and Multiple Frequency networks. Further, gapfiller deployment to provide digital television signal in challenged areas within the networks like mountain valleys. The actual signal field strength measurement was done to compare actual signal field strength a particular area to predicted (map coverage) signal strength with the hope of improving the propagation model.

The fundamental to the digital television system is technical data collection, which is amalgamated across the network within an ecosystem. This requires instrumenting network, data management, analysis and applications, or associated equipment to generate and provide credible outcome of the system. Therefore, simulation results are crucial to glean the maximum amount of information from each set of outcome so that accurate conclusions can be drawn and employed to make critical design decisions of systems. The actual signal field strength measurement must be evaluated and analysed the discrepancies noted between the ideal and actual situations.

In this dissertation, WRAP Version 4.8.1 management software was used to determine the coverage map predictions for gapfillers, single and multiple frequency networks for DTT transmission networks carried out in phase 1 implementation of DTT in Zambia and also Portable TV test receiver was used for signal field strength measurements in order to compare with simulated results. The Portable TV test receive, specifically, measured Signal Field Strength in $\text{dB}\mu\text{V}/\text{m}$, modulation error rate (MER) in dB, bit error rate (BER) and signal-to-noise ratio.

3.1 WRAP Version 4.8.1 management software

The management software deployed in this study is the WRAP VERSION 4.8.2 registered trademark of WRAP international of the ITU. The simulation parameters and configuration for the digital television reception scenario have been chosen with respect to DVB T2 model parameters. The software applies link budget parameter inputs, i.e. all parameters associated with the transmitter through transmission media to the receiver. The software is capable of calculating and providing coverage map predictions of digital television transmission. It collaborates with Google map software ready to provide result with reference to the actual geographical terrain or topography of a particular area under study. The management software tool considers the following as critical input parameters in order to generate coverage map prediction;

- i. Transmitter operating frequency,
- ii. Rated power of the transmitter
- iii. Modulation type
- iv. Effective isotropic radiated power of the transmitting antenna (EIRP),
- v. Geographical coordinates of antenna site
- vi. Polarization of antennas (vertical or horizontal),
- vii. Heights of the both antennas (transmit and receive),
- viii. Associated transmission line losses (including coaxial cables, filters and combiners) between the transmitter and the antenna
- ix. Refractivity of the atmosphere and effective earth curvature,
- x. Conductivity of the soil,
- xi. Relative permittivity or dielectric constant of the ground and the climatic conditions.
- xii. Free-space loss,
- xiii. Ground reflection coefficients,
- xiv. Fresnel-Kirchhoff parameters of diffraction.
- xv. Google Earth data (Data for the terrain elevation of the specific coverage calculation area.)

Appendix A shows the software management procedure. The simulation parameters and configurations for the coverage map prediction scenario have to be chosen with respect to DVB-T2 model parameters. The main features, parameters, settings and procedure of the heuristic WRAP Version 4.8.1 algorithm are considered in appendix A.

3.2 Signal Field strength measurement method

Materials used in this research study to measure signal field strength in selected locations around Lusaka, Southern, Central and Copperbelt Provinces are listed below:

- i. Global positioning system instrument
- ii. Portable TV test receiver
- iii. Receiving antennas (standard, outdoor, indoor)
- iv. Coaxial cables



Figure 3.1: (a) Portable TV test receiver (b) Standard and outdoor antennas (c) Indoor antenna

Procedure

The following procedure was employed at each test location to measure and record signal field strength during the verification exercise:

- i. The portable TV test receiver calibration was checked.
- ii. Coaxial cable was used to connect receiving antenna to portable TV test receiver.
- iii. For the standard and outdoor (Yagi) antennas were elevated to a height of at least above the roof top.
- iv. The receiving antenna was oriented to obtain maximum digital signal level from the direction of the transmitter.
- v. The carrier-to-noise ratio was also checked on the portable TV test receiver.
- vi. The actual measuring location was marked on the topographic map using GPS.
- vii. MER, BER and signal field strength measurement readings were taken and recorded.

3.3 Summary

This Chapter discussed the use of WRAP Version 4.8.1 management Software to predict the actual DTT coverage area of Phase 1 DTT implementation in Zambia. The simulation procedure for the management software is articulated in Appendix A. Also signal field strength measurement procedure is explained in this chapter as well.

CHAPTER FOUR

DATA COLLECTION AND ANALYSIS

4.0 Introduction

The purpose of this chapter is to outline and evaluate the findings which were uncovered during the process of evaluating digital television implementation and also signal field strength observation considering the uneven Zambian topology. The chapter is divided into two broad sections. Firstly, the chapter presents the analysis of findings concerning software management tool simulations and extent of digital television coverage footprint. This section presents coverage map predictions and technological factors in the digital television implementation process. Secondly, this chapter discusses the level of signal strength and type of digital television receiving equipment needed with respect to the geographical position of the receiver. To this end, this section illustrates by means of simulation results, DTT reception and recommended different types of antennas that can be used in order to lock DTT signal. Finally, the chapter evaluates whether or not digital television will cover the intended areas and contribute to universal access and/or bridge the gap of digital divide. In doing so, the chapter divulges different kinds of technological challenges and recommendations which would promote or hinder full digital television coverage in Zambia.

4.1 SCENARIO 1: Antenna Radiating Patterns

Antennas play an important role in wireless communication for radio frequency signals to be transmitted out or received. Important characteristics of the antenna are taken into considerations such as:

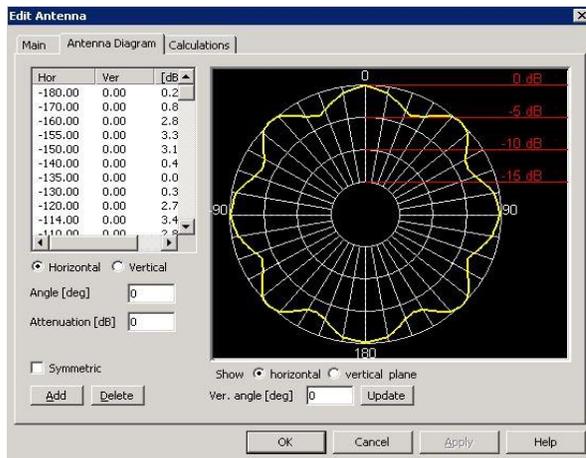
- i. Radiation Pattern and Intensity
- ii. Directive gain or Directivity
- iii. Power Gain and Efficiency
- iv. Operating frequencies

Table 4.1 shows the parameters for the simulation of antenna radiation pattern from the transmitter antenna geographically positioned during the experiment. Simulations were done for both vertical and horizontal radiation patterns. The simulation procedure for the software for antenna can be referred to appendix B.

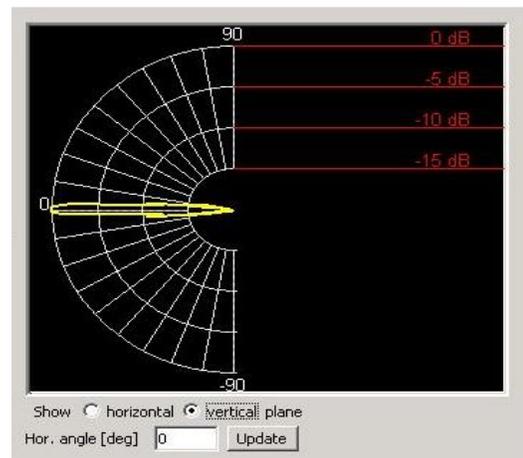
Table 4.1: Antenna input parameters

Antenna type	Kathrine PHP-8*4 UHF
Frequency range	480-862 MHz
Polarization	Horizontal/vertical
Cross polarisation	20dB
Maximum gain	16.65dB
Antenna Tilt	0 degree
Attenuation in dB	0 dB
Input power	5.2kW
EIRP	17.5kW
Antenna bays	8 x 4 UHF bay
Antenna azimuth	0

As it can be observed from simulation results in Figure 4.1a, antenna radiating system provided 360 degrees isotropic radiation about the transmitter mast and equal in all directions for horizontal polarization plane and Figure 4.2b for vertical polarization plane, respectively. Depending on the model of propagation preferred, the antenna radiating pattern can either be horizontal or vertical polarised or circular polarised.



(a) Horizontal pattern



(b) Vertical pattern

Figure 4.1: Parameters and antenna patterns

It should be taken into consideration and noted that antenna radiating patterns for all sites, remained unchanged during the simulation process though different transmitter powers were used. Horizontal and vertical planes of the transmitting sites during simulation were identical because

similar *Katherin* antenna type were used for high power transmitters at Kitwe, Senkobo, Pemba, Lusaka and Kapiri Mposhi and super turnstile antenna for Kalomo, Ndola, Kafue and Chingola gapfiller transmitter.

Since the simulations were performed by different transmitter powers per site, particular carrier-to-noise ratio (C/N) values that were used for the calculations were not necessarily the same nor do they necessarily coincide with the standard values referred to in Chapter Three

4.2 Multiple Frequency Network Simulation

A multiple frequency network (MFN) is a network in which multiple radio frequencies are allocated to each transmitter to cover particular areas. In order to cover large flat areas with one DVB-T2 transport stream signal, a certain number of channels are assigned per each transmitter. As alluded to in Chapter Three on the DTT implementation plan in Zambia, the following areas are MFN transmitting stations; Pemba, Senkobo, Kalomo and Kapiri Mposhi. Each transmitter is allocated 8MHz and total of 32MHz bandwidth is occupied by the four transmitters. The transmitter technical specifications were the same for these high power transmitters along the line-of-rail.

4.2.1 SCENARIO 2: Lusaka DTT MFN transmitter

Table 4.2 shows key software parameter inputs for Lusaka DTT transmitter which were used for simulation to generate coverage map prediction operating as a Multiple Frequency Network transmitting station and not in the SFN set up.

Table 4.2: Lusaka DTT coverage map prediction Parameter details

Parameters	Lusaka
Location (coordinates)	15°24'23.89"S, 28°19'20.86"E
Transmitter Power (TX)	7.7kW
ERIP	17.24kW
Modulation Mode	256QAM
FFT	32K
Code Rate	3/5
Data rate	37Mbps
Guard Interval	1/16
Pilot Pattern (PP)	4
Antenna mast height	91m
Antenna System Gain	13.5dBi
Receive antenna Gain	0dB
Feeder cable loss	1dB
Receive antenna Height	10m (above the roof top)
Frequency	682MHz
Antenna	8 x 4 UHF bay
Antenna Tilt	0.5 degrees
Polarisation	Horizontal
Propagation Model	ITU-R -525
Ground Height	1265m above sea level

Figure 4.2 shows the simulation results that red, green and blue colours indicate the level of coverage and field signal strength, with red indicating average signal field strength of 81.0 dB μ V/M, green being 69.0 dB μ V/M and blue being 53.0 dB μ V/M, respectively. It can be observed that the signal strength was much stronger nearer the transmitter at 81.0 dB μ V/M and reduces, gradually, as you move away from the transmitter. It was, further, noticed that for red indication, indoor receiving antennas can be used to pick up DTT signal. The green indication at 69.0 dB μ V/M, indoor or outdoor receiving YAGI UHF antennas can be deployed while for blue indication at 53.0 dB μ V/M, exclusively, external UHF YAGI antennas are the most recommended in order to lock to the DTT signal. It was also noted that the further away from the transmitting antenna, the higher the height of the receiving antenna to rock the DTT signal. That could have been attributed to topography of the area and path profile obstructions like tall buildings and mountains between transmitting and receiving antennas.

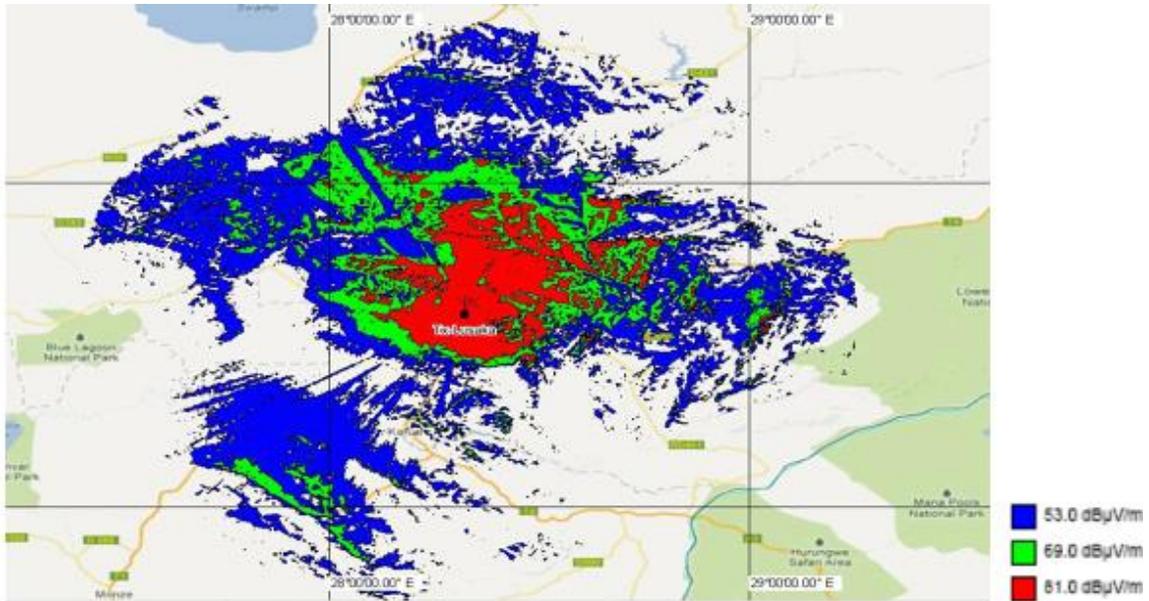


Figure 4.2: Lusaka DTT coverage map prediction

However, from the simulation results and with reference to Figure 4.2, there were some isolated cases identified where the Lusaka DTT field strength alone cannot provide signal coverage due to the geographical terrain such as areas like Kafue, Chilanga, Chisamba and Chibombo. It can be emphasized by considering the path profile between Lusaka and Kafue in Figure 4.3. Around 1280m above sea level and almost 15km line-of-sight from Lusaka, television signal can be blocked by the area around Chilanga Cement Factory resulting in places between Chilanga and Kafue not receiving terrestrial digital television signal from Lusaka DTT transmitter as illustrated in Figure 4.3 due to uneven path signal profile between Lusaka and Kafue. It should be noted that DTT signal depends on line-of-sight propagation between transmitting and the receiving antennas. With reference to Lusaka DTT transmitter, it is at 1267m above sea level with an added transmitter mast height of 91m. The receiving antenna at Kafue DTT transmitting site at 1210m above sea level with a UHF YAGI receiving antenna was elevated to about 10m above the ground, the place did not receive the terrestrial transmitted signal from Lusaka transmitter because of mountain obstruction in the signal path between the two towns as illustrated in Figure 4.3.

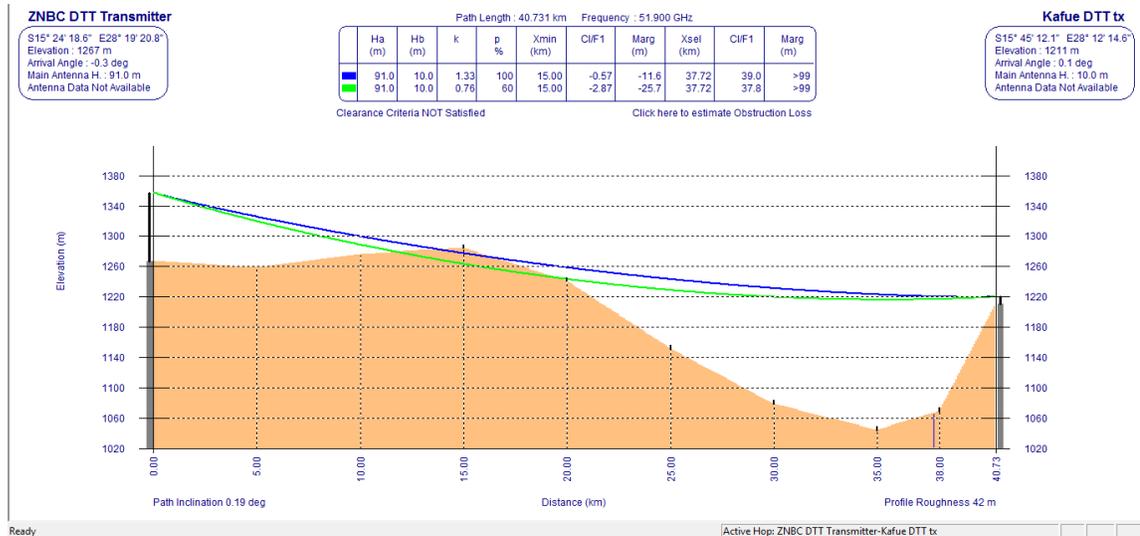


Figure 4.3: Geographical terrain between Lusaka and Kafue

Similarly, Chilanga failed to record minimum signal field strength because it is on the reward side of the mountain at the level of 1160m above the sea level. In order to provide signal coverage at Chilanga and Kafue, DTT gapfiller transmitters could be recommended and installed to service the areas because of the severe geographical terrain.

4.2.2 SCENARIO 3: Kapiri Mposhi DTT MFN transmitter (610MHz)

Figure 4.4 shows the coverage map prediction for a 5kW Kapiri Mposhi DTT transmitter. It is operating as a Multiple Frequency Network (MFN) transmitter at frequency allocation of 610MHz. From the simulation results obtained, the Kapiri Mposhi high power transmitter will, adequately, cover areas like Kapiri Mposhi central and its surrounding areas, Kabwe, some parts of Mkushi and Ndola rural, respectively. As it can be noted in Figure 4.4, most central part of Zambia would receive digital signal from Kapiri Mposhi DTT transmitter because the land is relatively flat. However, Chibombo area will be inadequately covered by Kapiri Mposhi field signal strength as shown in figure 4.4 below. A recommendation to install a gapfiller will be required in order to provide signal field strength in the area. The gapfiller transmitter can operate either as MFN or SFN set up.

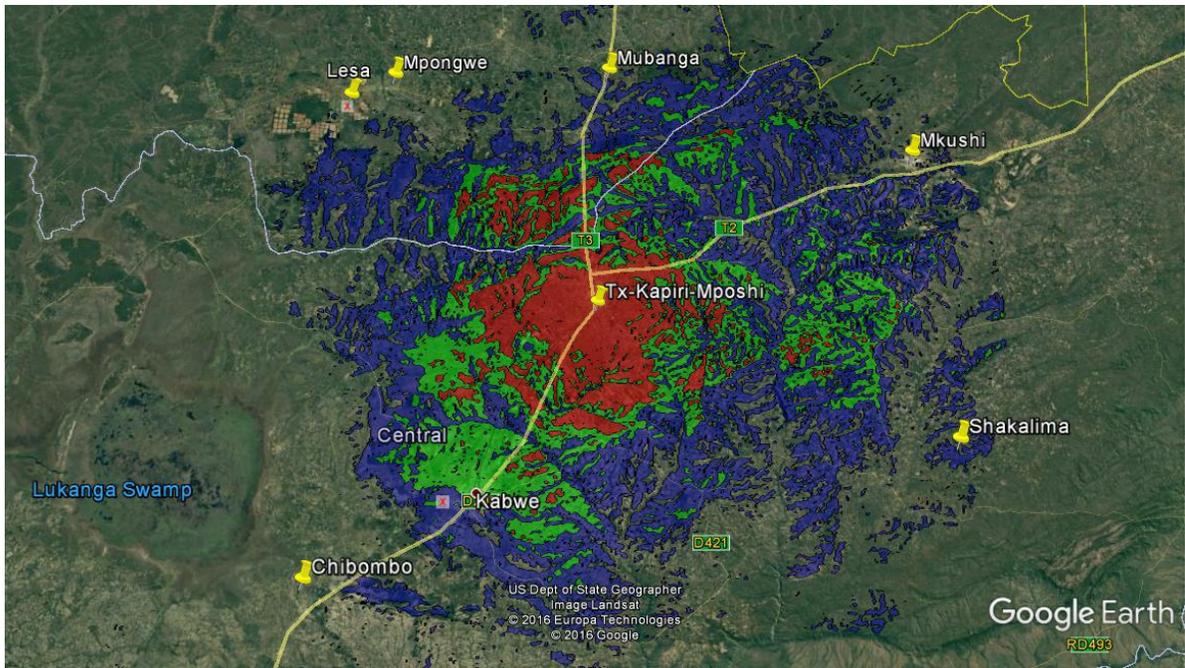


Figure 4.4: Kapiri Mposhi coverage map prediction

Figure 4.5 shows results for the path profile simulation between Kapiri Mposhi and Mkushi towns. It can be observed from coverage map prediction that the area is mountainous between the two towns. Only areas on higher lands like mountains will be able to receive signal field strength rather than lower areas (valleys) as projected by the Kapiri Mposhi – Mkushi path profile.

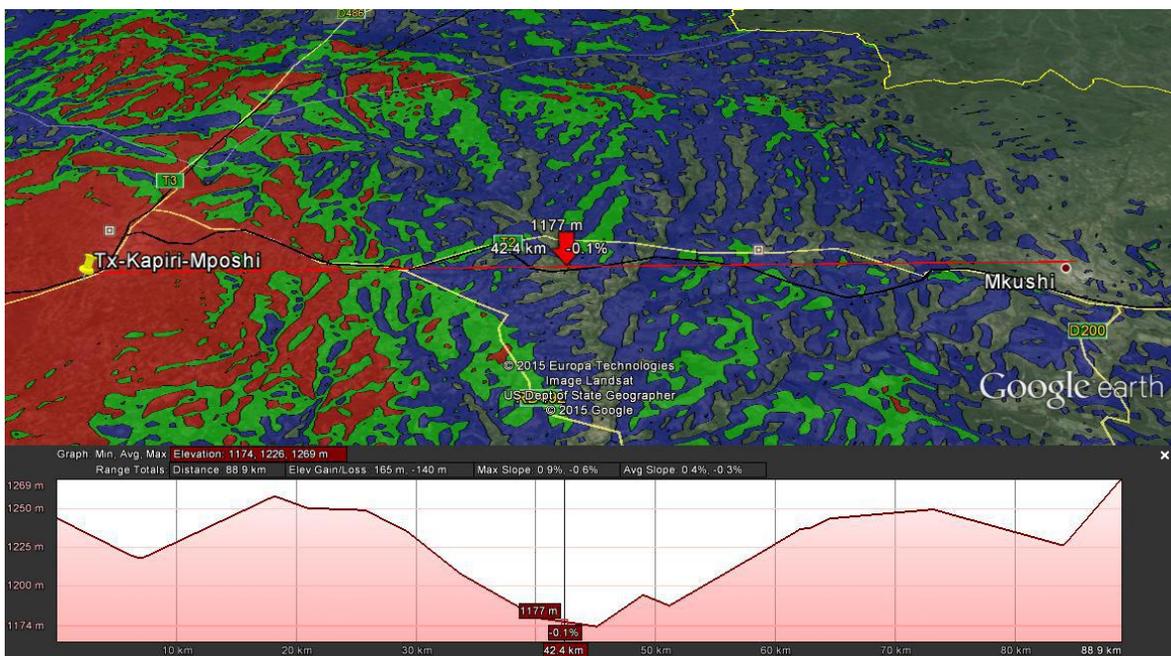


Figure 4.5: Kapiri Mposhi – Mkushi Path profile

4.2.3 SCENARIO 4: Pemba DTT MFN transmitter

Figure 4.6 shows simulation results for a 5kW Pemba DTT transmitter coverage map prediction. It operates as Multiple Frequency Network (MFN) at 562MHz. The transmitter will adequately service areas like Monze, Choma, Macha, Lochvinvar National Park, Manga and surrounding areas. However, Siavonga and along Lake Kariba shores will not be serviced by Pemba field signal strength because of the mountainous topological terrain which will obstruct terrestrial signal path profile. Satellite DTH signal or installing a gapfiller transmitter will be necessary to cover vulnerable areas under discussion. The gapfiller transmitter can either be connected in the SFN with Pemba DTT transmitter to avoid a new frequency allocation as the preservation of digital dividend or MFN with its own frequency. It can be further noted from the simulation in Figure 4.6 that Mazabuka, Magoye, Monga, Kalomo and surrounding areas will not be covered by Pemba transmitter signal due to geographical terrain. Most areas are found in the valleys of mountains as can be observed from the figure 4.6. Choma and Monze areas can receive digital television signal from Pemba Transmitters, sufficiently.

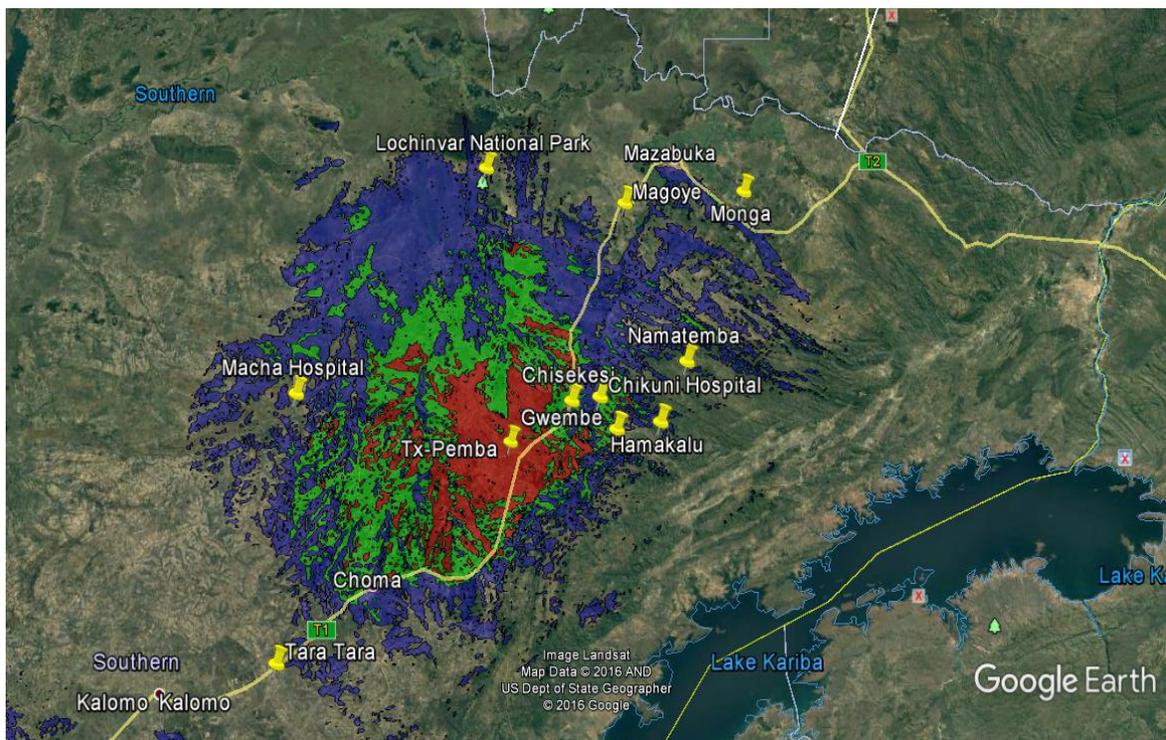


Figure 4.6: Pemba transmitter coverage prediction map

4.2.4 SCENARIO 5: Senkobo DTT MFN transmitter

It can be observed that the transmitter field strength at Senkobo will cover Livingstone and areas across Zambezi River into Zimbabwe as illustrated in Figure 4.7. However, Kalomo area will not receive digital signal from Senkobo transmitting site. In order to optimize front lobe into Zambian mainland, it is recommended that bays of transmitting antennas will be required to be oriented so that back lobe pattern into Zimbabwe is reduced to avoid possible signal interference into the neighbouring country. Also the reduction of the back lobe will enhance the front lobe to coverage more areas inland.

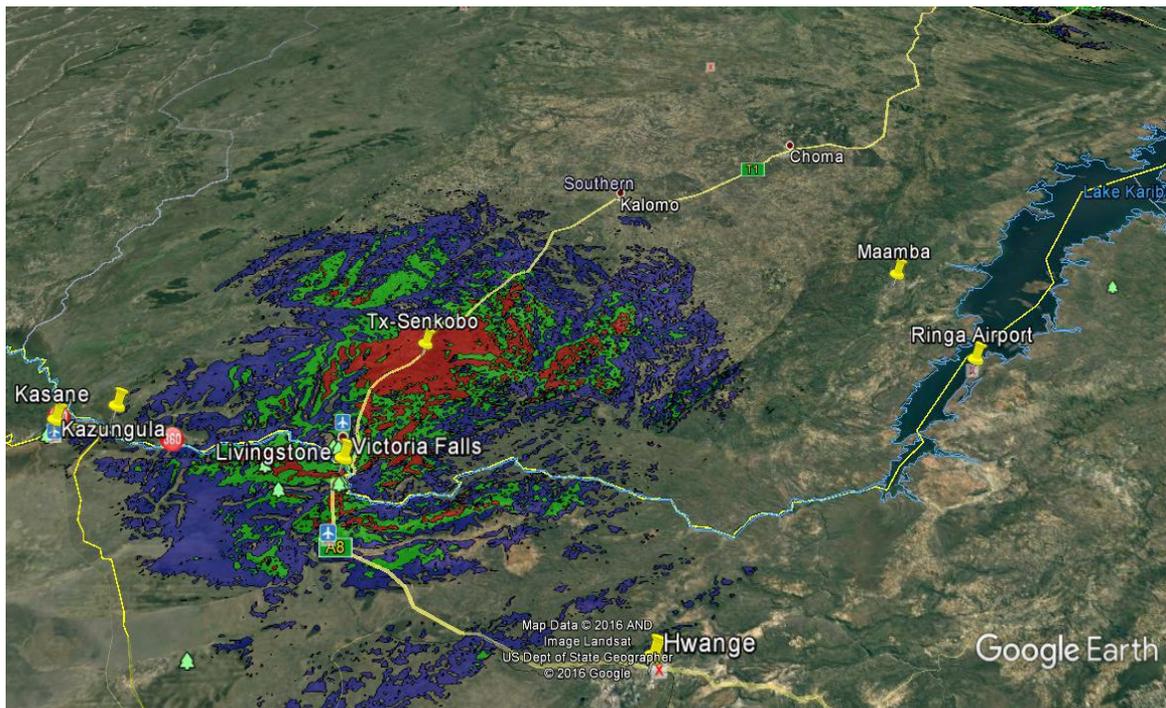


Figure 4.7: Senkobo transmitter coverage prediction map

4.2.5 SCENARIO 6: Gapfiller transmitter – Kalomo

Figure 4.8 shows the combination of simulation results for Pemba and Senkobo coverage map predictions. Senkobo and Pemba transmitter radiation patterns will not overlap and cover surrounding areas adequately. Kalomo area will not receive digital television signal from either Pemba or Senkobo transmitting sites, respectively, as illustrated in Figures 4.6 and 4.7. Pemba and Senkobo transmitters are found at 1184m and 1100m, while Kalomo at 1298m above ground level, the signal patterns from both transmitting stations will be obstructed by mountainous terrain as shown by the path profile between the two sites. Results

confirm that the difference in the elevations above sea level has significant effect on signal propagation across the uneven geographical terrain as shown in Figure 4.8.

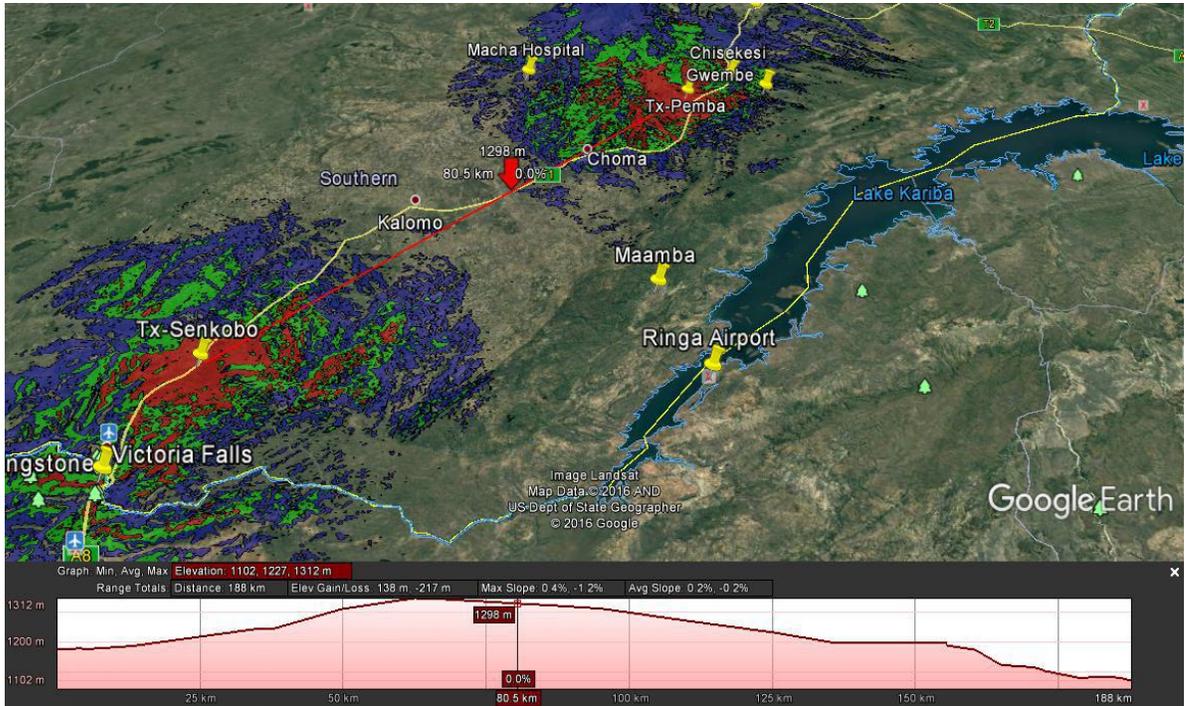


Figure 4.8: Senkobo and Pemba transmitter radiation patterns and path profile

In order to resolve the challenge at Kalomo area, a low power Kalomo DTT gapfiller transmitter will be needed to be installed between two high power Pemba and Senkobo signal coverage. Installation of gapfiller transmitter at Kalomo will ensure signal coverage of the areas and enhance signal coverage from Pemba through to Senkobo. As it can be observed from the simulation in Figure 4.9, low power transmitter at Kalomo transmitting site will produce a signal pattern that will overlap with Pemba and Senkobo radiation patterns resulting in covering the entire stretch from Pemba through to Livingstone. The challenge that was experienced in Figure 4.8, can be resolved and gapfiller will produce simulation results as shown in Figure 4.9. However, it should be noted that the gapfiller transmitter will not provide signal field strength to Siavonga, Lake Kariba and surrounding areas. It can be seen from the results and recommended that Siavonga area will require a gapfiller transmitter too. Otherwise, the area will depend on the direct-to-home satellite feed considering the geographical terrain.

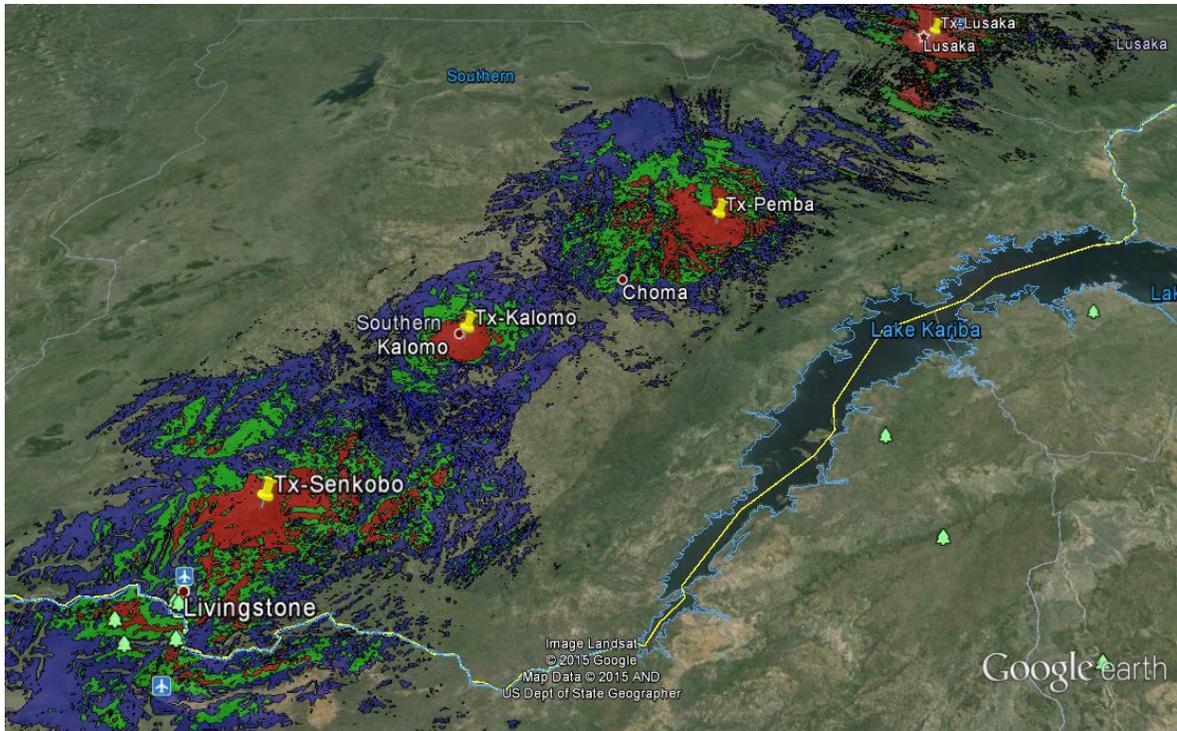


Figure 4.9: Kalomo gapfiller transmitter

4.2.6 Scenario 7: Technical challenges – Mazabuka

From simulation obtained in Figures 4.9 and 4.10, it showed that Mazabuka will not receive field signal strength despite being 40.8km from Lusaka and 22.4km from Kafue transmitting sites, respectively. As predicted by simulation results, the elevation of a higher land at 1029m above sea level along Kafue - Mazabuka path profile will block the digital television signal for Nega Nega, Lubombo and Mazabuka (1000m above sea level). Furthermore, it was noted from the results that Mazabuka could not, as well, receive digital television signal from Pemba DTT transmitter because of geographical terrain. Therefore, it will be advised that a gapfiller transmitter will be necessary to be installed at Mazabuka to provide digital TV signal to the area.

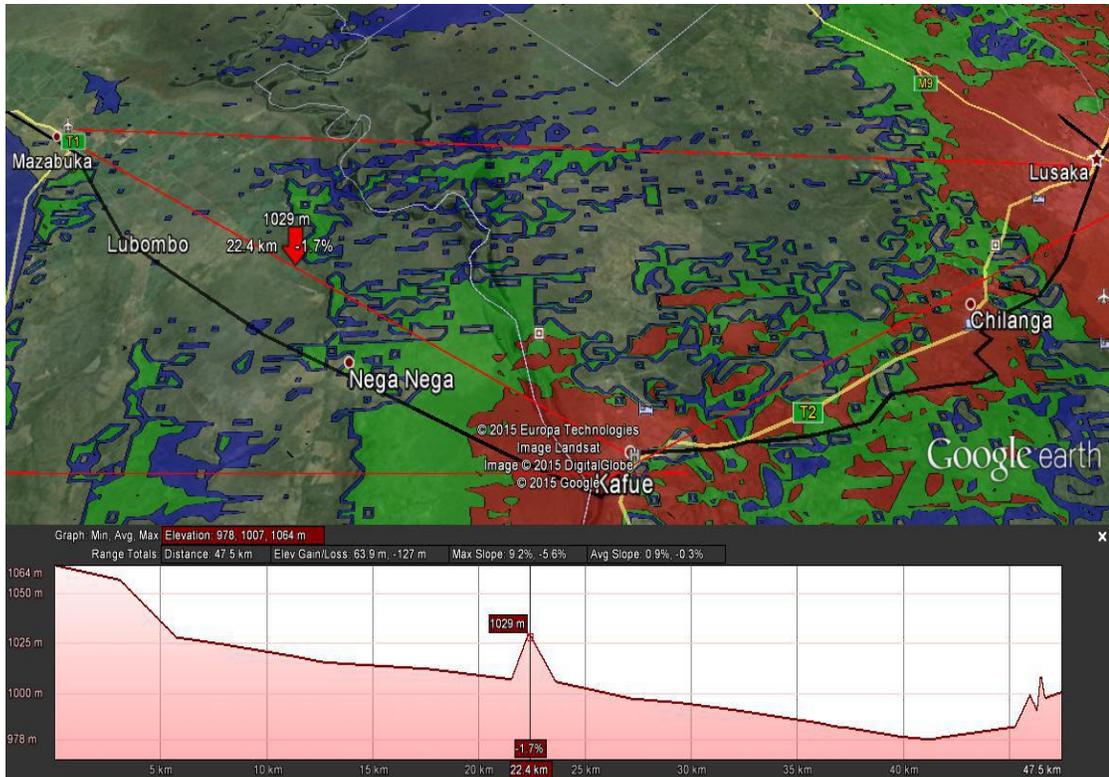


Figure 4.10: Kafue – Mazabuka path profile

4.3 Single Frequency Network Simulation

A Single Frequency Network (SFN) is a broadcast transmitter network consisting of transmitters with overlapping coverage areas that transmit same programmes at the same frequency at the same time. SFN allotments allow network coverage to be progressively modified or improved by adding further transmitters without the need for frequency re-planning or additional frequency allocation as long as the constraints of the frequency plan are respected. SFN makes it easier to improve signal coverage quality step by step, for example, when enhancing coverage for complex geographical terrain environments additional transmitters can be installed at same frequency.

There are two planned single frequency networks (Lusaka-Chilanga-Kafue and Ndola-Kitwe-Chingola) deployed in Zambia and are allocated frequency of 682MHz and 570MHz, respectively. It can be further elaborated that three transmitters per single frequency network will require 8MHz bandwidth occupation resulting into 16MHz total bandwidth for two networks. The application of SFN system will improve frequency optimisation and field signal strength in complex areas affected by geographical terrain and tall buildings. Two simulations scenarios for the SFN were

considered, namely, Lusaka-Chilanga-Kafue and Ndola-Kitwe-Chingola as will be illustrated in the simulation scenario 1 and scenario 2.

4.3.1 SCENARIO 8: Lusaka-Chilanga-Kafue Single Frequency Network

Table 4.3 shows the technical parameters used to generate coverage map prediction for Lusaka-Chilanga-Kafue single frequency network. Three transmitter parameters were used in the software to produce the signal coverage area for the Copperbelt SFN. It should be noted that different transmitter powers were used according to the proposed design for three transmitter. The procedure to produce the simulation is as indicated in Appendix A.

Table 4.3: Lusaka-Chilanga-Kafue SFN parameters

Location	Lusaka	Chilanga	Kafue
Coordinate	15°24'23.89"S, 28°19'20.86"E	15.58089S 28.27597E	15.75454S 28.20424E
Transmitter Power	7.7kW	100W	600W
System	DVB-T2	DVB-T2	DVB-T2
ERP	17.24kW	125W	750W
Modulation Mode	256 QAM	256 QAM	256 QAM
Guard Interval	1/16	1/16	1/16
Code rate	3/5	3/5	3/5
FFT	32K	32K	32K
Antenna Height	91m	80m	50m
Antenna System Gain	13.5dB	13.5dB	13.5dB
Receive antenna Gain	0dB	0dB	0dB
Rx antenna Height	10m	10m	10m
Frequency	682MHz	682MHz	682MHz
Antenna (8 panels)	8,8,8,8 (4 bay)	Super turnstile Antenna	Super turnstile Antenna
Propagation Model	ITU-R -525	Isotropic	Isotropic

Figure 4.11 shows simulation for coverage map prediction for Lusaka-Chilanga-Kafue SFN. Three DTT transmitters were installed in Lusaka as main transmitter, Chilanga and Kafue as gapfiller transmitters that will operate as Single Frequency Network at 682MHz with different effective isotropic radiated power (EIRP), respectively. It can be observed from the simulations that in order to enhance and optimize signal coverage for Lusaka and the surrounding area, installation of low power transmitters (gapfillers) at Kafue and

Chilanga would resolve signal challenges that could be confronted with DTT reception as in Scenario 1 of MFN analysis. Most of the complex areas that could not be serviced by Lusaka MFN transmission alone, will be achieved by Lusaka-Chilanga-Kafue SFN signal coverage as illustrated in Figure 4.11.

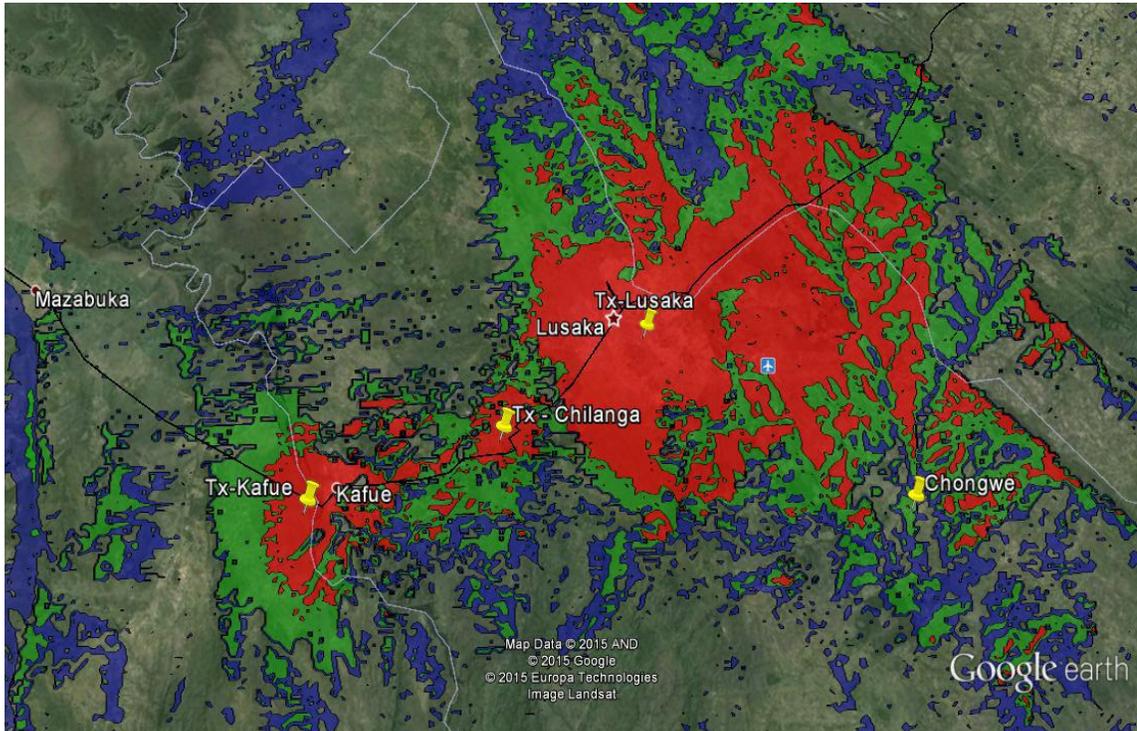


Figure 4.11: Lusaka-Chilanga-Kafue single frequency network

It can be further deduced from Figure 4.11 that geographical terrain challenges that could have affected signal field strength reception from Lusaka MFN, will be resolved because Chilanga and Kafue DTT gapfiller transmitters will cover respective areas sufficiently and overlap with Lusaka DTT transmission in SFN transmission. However, it can be further observed from the simulations that some places like Mazabuka, southwest of Lusaka, west of Chilanga and northeast of Kafue could not be covered by the Lusaka-Chilanga-Kafue SFN. Those areas are mountainous and posed a technical challenge for signal propagation and minimum signal field strength reception. Recommendation will be necessary for the installation of lower power transmitters in vulnerable areas in order to optimize DTT implementation process of phase 1. From our recommendation, TV users will be required to install Ku-satellite equipment in order to access a DTH signal via the satellite transmission. Figure 4.12 illustrates Lusaka-Kafue path profile and Lusaka-Chilanga-

Kafue SFN coverage area, it can be seen from the figure that geographical terrain challenges will not affect field signal strength in the SFN coverage area. Despite the differences in the elevation above sea levels as can be observed in the path profile below, field signal strength for TV reception will be good and mostly indoor receiving antennas will be deployed.

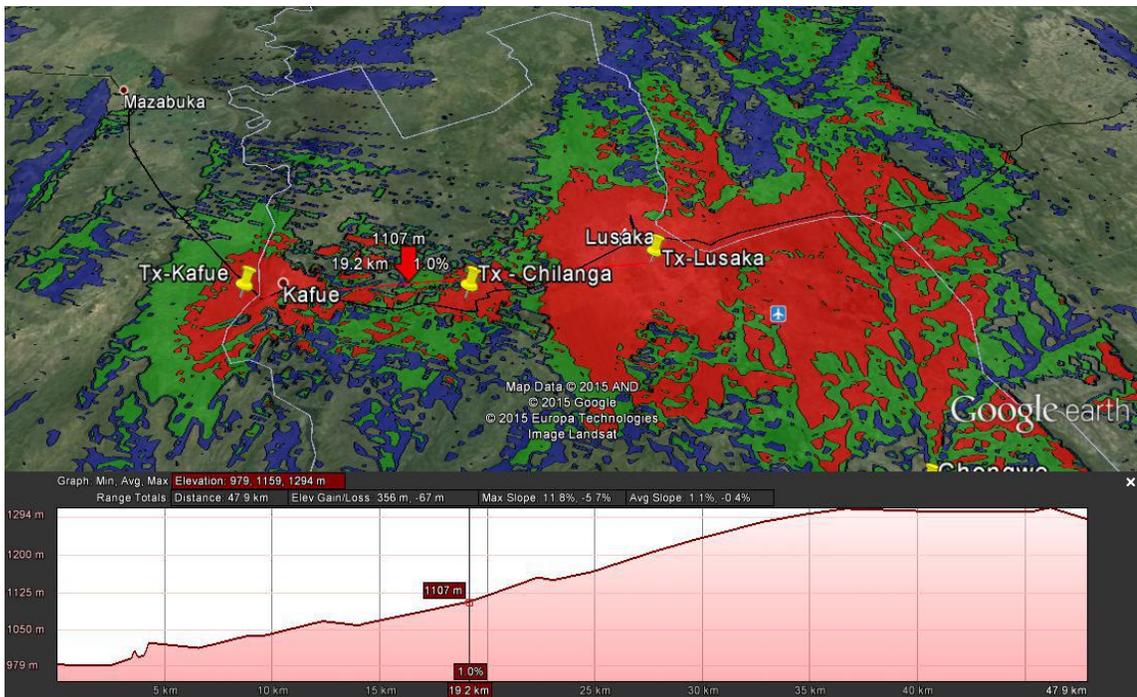


Figure 4.12. Lusaka-Kafue path profile and coverage map prediction

4.3.2 Scenario 9: Ndola-Kitwe-Chingola SFN

Table 4.4 shows the technical parameters employed to generate coverage map prediction for Ndola-Kitwe-Chingola single frequency network. Three transmitter parameters were used in the software management tool to produce predicted signal coverage area for the Copperbelt SFN. It should be noted that different transmitter powers accordingly were used according to the proposed design of the DTT project for three SFN transmitters.

Table 4.4: Ndola-Kitwe-Chingola SFN parameters

Location	Ndola	Kitwe	Chingola
Coordinate	13.04954S, 28.67263E	12.78868S, 28.2270E	12.52615S, 27.8917E
Transmitter Power	500w	7.7kW	500w
ERP	750w	17.24kW	125w
System	DVB-T2	DVB-T2	DVB-T2
Modulation Mode	256QAM	256QAM	256QAM
Pilot Pattern	PP4	PP4	PP4
Guard interval	1/16	1/16	1/16
Code rate	3/5	3/5	3/5
FFT	32K	32K	32K
Antenna Height	50m	100m	80m
Antenna Gain	13.5dB	13.5dB	13.5dB
Rx Antenna Gain	0dB	0dB	0dB
Rx antenna Height	10m	10m	10m
Frequency	570MHz	570MHz	570MHz
Antenna (8 panels)	Super turnstile Antenna	8 x 4 UHF bay	Super turnstile Antenna
Propagation Model	ITU-R -525	Isotopic	Isotopic

Figure 4.13 shows simulation of Ndola-Kitwe-Chingola SFN on the Copperbelt province of Zambia. Three transmitters are installed at Kitwe (5kW), Ndola (500w) and Chingola (100w), respectively. The three transmitters operate in SFN and provide overlapping coverage signal areas that will transmit same programmes in the same frequency channel at the same time. From simulation results, it was noted that coverage map prediction for the area under consideration will provide adequate signal field strength to most of Copperbelt towns including part of Democratic Republic e.g. Sakania and Mokambo. However, it should be considered that the digital signal will spill over into the neighbouring country might cause signal interference in that country. Hence, it will be recommended that orientation of the SFN radiating antennas is necessary to reduce back lobe into the foreign country and improve the front lobe into Zambia mainland. The signal field strength is enough to lock to digital television in most Copperbelt areas.

From results obtained, it is seen that Ndola-Kitwe-Chingola SFN and Kapiri Mposhi MFN digital TV signal will overlap and TV viewers will be able to tune to either one of the two networks as illustrated in Figure 4.13.

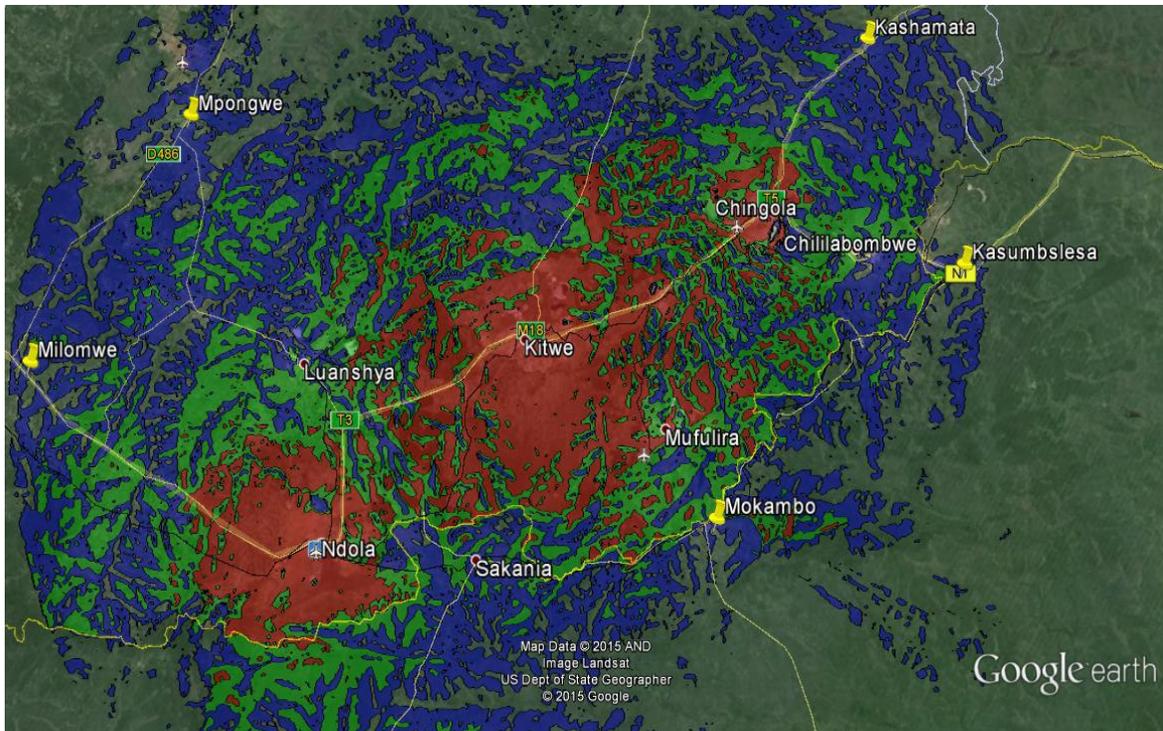


Figure 4.13: Ndola-Kitwe-Chingola SFN coverage map prediction

It can be further observed from simulation results in Figure 4.13 that path profile between Ndola and Chingola is uneven and can pose a technical challenge if MFN were to be implemented at Kitwe transmitting station for Copperbelt signal coverage. Therefore, application of Ndola-Kitwe-Chingola SFN provides adequate signal strength level to Copperbelt towns despite the geographical terrain, heaps of copper slags in mining towns and tall buildings that affect line-of-sight signal propagation if the MFN is to be deployed. SFN provides more advantages than MFN such as the bandwidth occupation. Three transmitters can only occupy 8MHz as compared to three MFN transmitters each with 8MHz resulting into 24MHz bandwidth occupation. It can, further, be noted that in single frequency networks, there is frequency spectrum saving as compared to the MFN and coverage area is enhanced in SFN as compared to the latter.

It can be further observed from Figure 4.14 that the land depression between Ndola and Chingola will not affect the signal distribution around Kitwe and its surrounding areas because Kitwe DDT transmitter's RF signal will overlap with both Ndola and Chingola transmitter's RF signals. A large guard interval setting will be required so that delayed signals

to the receiver can be used constructively and not to cause signal interference if small guard interval were used.

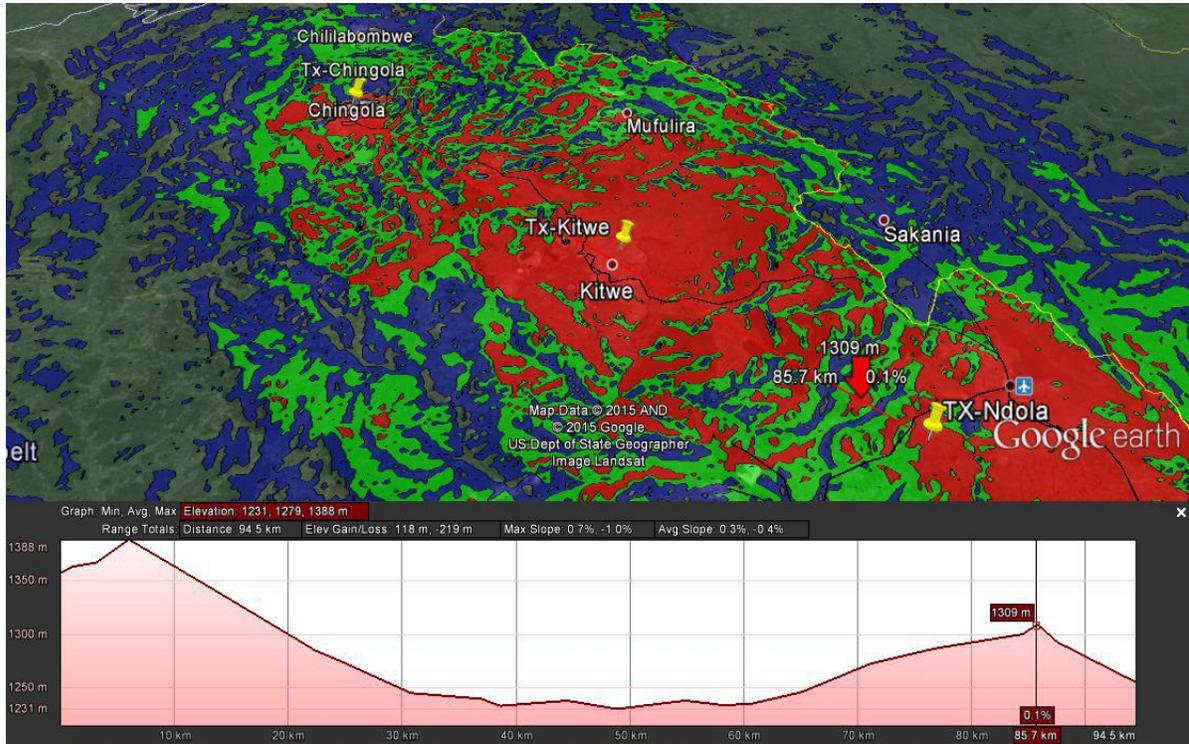


Figure 4.14: Ndola-Chingola path profile

4.4 The Overall footprint of Phase 1 DTT implementation

Figure 4.15 shows the overall simulation for phase 1 DTT footprint in Zambia along the line of rail from Chililabombwe to Livingstone. It can be learned from the coverage map prediction that most of towns will be covered along the line-of-rail. However, from the overall simulation of Figure 4.15, it can be observed that some areas between Kabwe and Lusaka and also between Kafue and Pemba that cannot be covered by digital terrestrial transmission from any transmitting areas, for example, Chisamba, Chibombo and Mazabuka. It is recommend that Chibombo and Mazabuka will require gapfiller transmitters to overlap with Kapiri Mposhi and Pemba DTT transmitters' RF signals, respectively. Otherwise, TV viewers will require to install Ku-band satellite equipment in order to receive a DTH signal which is expensive for the ordinary Zambian.

The overall coverage map prediction in Figure 4.15, clearly shows how phase 1 DTT implementation in Zambia will require optimisation to provide effective signal field strength along the line of rail, otherwise few towns will not be serviced and will only depend on DTH signal.

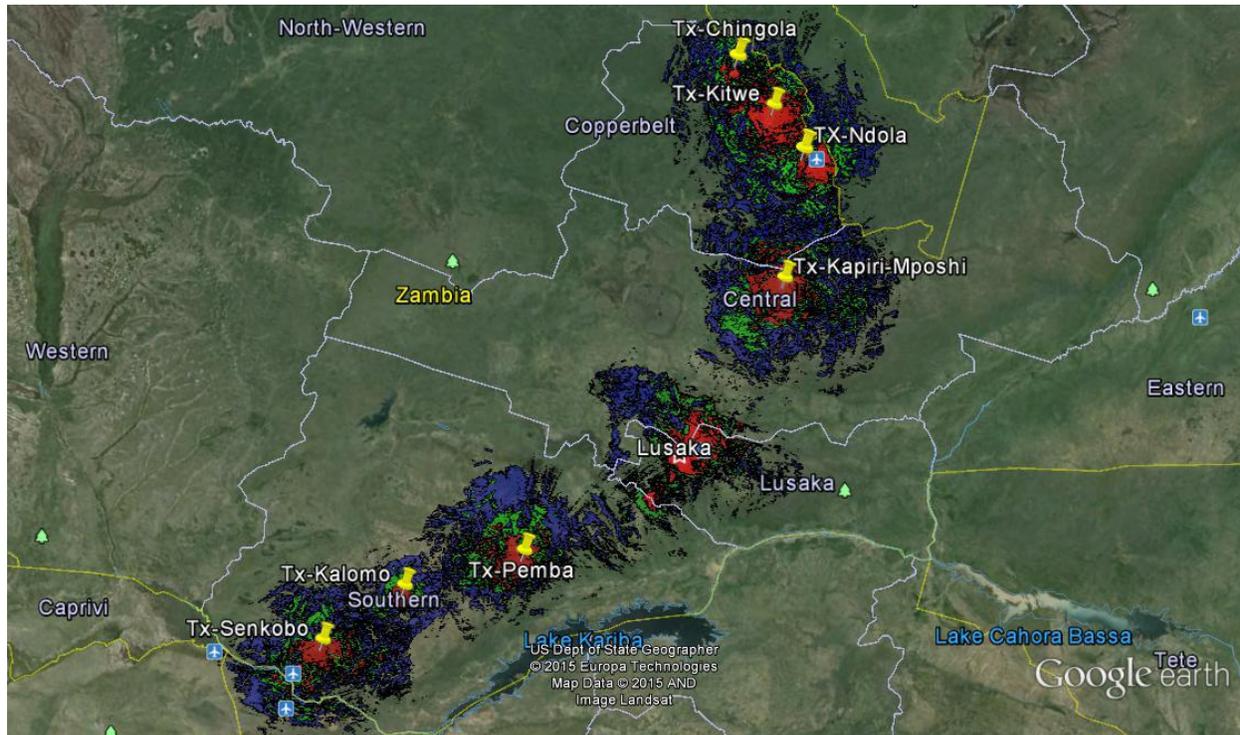


Figure 4.15: Footprint for Phase 1 DTT implementation in Zambia

4.5 Signal Field strength Measurements

Signal field strength measurement of the received DTV signal needs to be done for two main purposes. The first one is to compare actual to predicted signal field strength coverage in view of improving propagation model. The second one is to establish where and why a DTT signal field strength cannot be reliably received. The engineering planning unit needs to know this in order to consider remedial action and also, to advise its end users on what type of receiving antennas needed to capture the signal.

The antenna receives the electromagnetic energy of a television signal and converts it into electrical energy and vice versa. The effectiveness of receiving antennas is determined both by factors intrinsic to the specific antenna design and by external factors. With regard to the former, antennas are designed with varying amounts of antenna gain or directivity. The greater the gain of a

receiving antenna is, the greater the antenna's ability to capture weak signals. However, there is a significant tradeoff when incorporating additional gain in an antenna design. That is, designing an antenna with greater gain requires that it also be designed to have a narrower beamwidth, these antennas are called standard or precision antennas. With regard to external factors, considerations relating to antenna placement and orientation affect the ability of a household to receive an adequate DTV signal. For example, because structures located within the line of sight between transmitter and receiving antenna can block or weaken the strength of received signals, an outdoor antenna installation, such as on a rooftop, will generally allow a stronger signal to be received by the antenna than will an indoor antenna installation. Thus, for households located in the same general area, an indoor reception will generally need an antenna with greater gain than will be for household in which the antenna is placed outdoors. If an antenna is oriented/directed so that its maximum gain is not focused on the desired TV signal, the received energy from that station's signal will be much lower. In order to measure coverage area, it is preferable to determine margin i.e. BER and MER, rather than determining field strength alone, because it tells more about whether a transmitted signal can be received or not.

During field signal strength measurement exercise, the sources (transmitting antennas) are positioned at a specific elevation above average terrain and transmitting at a specific power level. Presence of trees, tall buildings, and terrain irregularities result in large measured signal variations from location to location even within relatively small areas. Further, it should be clearly understood that the quality of DTT service at any given location is a function not only of signal field strength, but it is also a function of receiver signal-to-noise ratio, sensitivity, receiving antenna gain and antenna orientation, transmission line loss and spurious RF emissions interference.

Three types of receiving antennas namely standard, outdoor and indoor antennas were used to determine signal field strength, bit error rate, modulation error rate and carrier-to-noise ratio. Portable TV test meter was used in order to ascertain the suitability of different types of antennas to be used in DTT reception. The standard (precision) and outdoor (ordinary) receiving antennas were connected and oriented together at the almost same height as illustrated in the Figure 4.16 (a) and Figure 4.16 (b). The precision Yagi antenna being on top of the pole and ordinary few centimeters below it.



(a)

(b)

Figure 4.16: (a) Antenna orientation (b) Standard and outdoor (Yagi) antennas

4.5.1 Outdoor (Yagi) antenna advantages

The outdoor Yagi antenna is a particularly useful form of RF antenna design. It is widely used in applications where RF antenna design is required to provide gain and directivity. In this way the optimum transmission and reception conditions can be obtained. The Yagi antenna provides many advantages in a number of applications such as:

- i. Antenna gain allowing lower strength signals to be received.
- ii. Directivity enabling interference levels to be minimised.
- iii. The construction enables the antenna to be mounted easily on vertical and other poles with standard mechanical fixings.

4.5.1.1 Measured values of Received Signal

The actual signal field strength results varied from point to point during the survey influenced by a variety factors, including, but not limited to, location of the receiving equipment, building obstructions, mountains and trees, specific reception hardware and receiving antenna orientation. Table 4.5 provides information for the following:

- i. Actual coordinates where the signal tests were done, elevation above sea level and distance from point of reference (Lusaka digital transmitter).
- ii. Indoor, outdoor and standard antennas were used at any particular test point in order to obtain results for signal field strength (SFS), bit error rate (BER) and modulation error ratio (MER).
- iii. Red indication in the Table 4.5 shows that the SFS was strong and indoor antennas can be used to receive DTT signal while blue indication only outdoor antennas can be used.
- iv. Green indication illustrates that indoor or outdoor antennas can be used and depends on the orientation of the antenna towards the transmitter.
- v. White indication in the table shows lack of DTT signal presence in those areas because none of the three receiving antennas captured the digital television signal. Hence, those areas can be covered only by Direct-To-Home (DTH) satellite feed or the installation of gap filler transmitter.
- vi. The predicted values from simulations were that red, green and blue colours indicated the average coverage signal level (expected field signal strength) with red being above **70.0 dB μ V/M**, green being **69.0 dB μ V/M** and blue on **53.0 dB μ** .

Table 4.5: Field signal strength measurement

SFN Frequency: 682MHz Power: Lusaka(5kW); Chilanga (500W); Kafue (100W)								
Test equipment		RS EFL340,Standard Antenna (900E), Outdoor Antenna Indoor Antenna, Portable TV Receiver						
Test Points on the Google Map	GPS Readings				Antenna Type	Portable TV Test Receiver		
	Latitude	Longitude	Elevation (meters)	Distance from the Lusaka DTT Antenna (Km)		Field Signal Strength (dBμV)	BCH BER	MER (dB)
1	15°44'37"	28°9'10"	999	5.64	Standard Antenna	70.1	<1.0E-8	35
					Outdoor Antenna	71.8	<1.0E-8	35
					Indoor Antenna	46.8	<1.0E-8	<16
2	15°45'46"	28°10'42"	997	2.29	Standard Antenna	73.2	<1.0E-8	>35
					Outdoor Antenna	75.5	<1.0E-8	>35
					Indoor Antenna	50.9	<1.0E-8	20
3	15°46'34"	28°10'38"	988	3.75	Standard Antenna	68.5	<1.0E-8	35
					Outdoor Antenna	70.3	<1.0E-8	>35
					Indoor Antenna	46.2	<1.0E-8	20.6
4	15°36'24"	28°15'41"	1160	17.47	Standard Antenna	44.2	<1.0E-8	21.4
					Outdoor Antenna	43.7	<1.0E-8	21.5
					Indoor Antenna			
5	15°12'36"	28°15'0"	1133	23.10	Standard Antenna	43.3	<1.0E-8	19.9
					Outdoor Antenna	41.2	<1.0E-8	19.6
					Indoor Antenna			
6	15°10'2"	28°14'24"	1124	27.94	Standard Antenna	58.0	<1.0E-8	30.2
					Outdoor Antenna	58.4	<1.0E-8	27.8
					Indoor Antenna			
7	15°4'47"	28°12'22"	1133	38.27	Standard Antenna	54.5	<1.0E-8	28.5
					Outdoor Antenna	55.7	<1.0E-8	28
					Indoor Antenna	40.6	<1.0E-8	16.8
8	15°0'40"	28°10'56"	1138	46.28	Standard Antenna	61.0	<1.0E-8	31.6
					Outdoor Antenna	61.5	<1.0E-8	31.2
					Indoor Antenna	36.1		
9	14°55'39"	28°5'7"	1182	58.82	Standard Antenna	66.4	<1.0E-8	31.8
					Outdoor Antenna	66.6	<1.0E-8	31.8
					Indoor Antenna	50.4	<1.0E-8	27.3
10	14°47'31"	28°3'18"	1182	73.86	Standard Antenna	Nil	Nil	Nil
					Outdoor Antenna	Nil	Nil	Nil
					Indoor Antenna	Nil	Nil	Nil

From Table 4.5, the following can be observed as follows;

- a) Portable TV test receiver measured the following:
 - i. **Signal Field strength** – the magnitude of an electric field at a reference point, which is located at a significant distance from the transmitting antenna. This is expressed in terms of the received signal power by the receiver or the voltage per length received by the reference antenna and measured in dBμV.

- ii. **Bit error rate (BER)** – the number of received binary bits that have been changed due to noise and interference, divided by the total number of transferred bits during a studied time interval in digital transmission. . For instance, if a 1 is transmitted and it's subsequently received as a 0, the result is a bit error.

$$\text{BER} = \frac{\text{Number of errored bits}}{\text{Total number of bits recieved}}$$

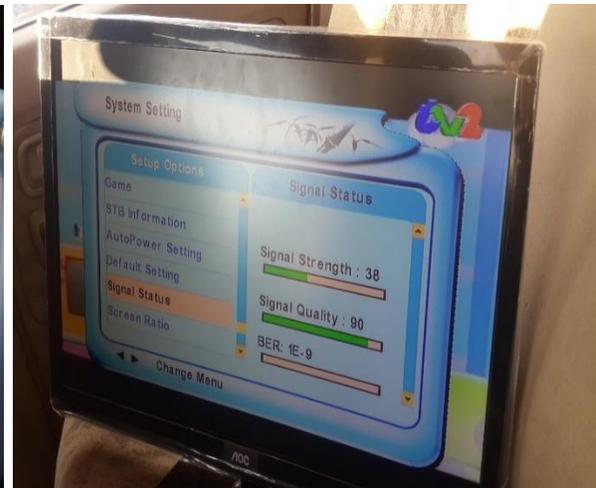
BER is a unitless performance measurement, often expressed as a percentage number. The lower the Bit Error Rate, the better the quality of received signal. For a given STB measurement, if BER is zero then it indicates that no binary bit was received and the STB will show error messages.

- iii. **Modulation error rate (MER)** - a measure of the signal-to-noise ratio (SNR) in a digitally modulated signal. Thus, it indicates the figure of merit for a vector-modulated signal (such as a COFDM signal). It is expressed in dB and permits a receiver to provide a figure of merit for the COFDM carrier ensemble. A high MER value indicates good signal quality. In practice, the MER lies in the range of 0 dB to 40 dB when receiving digital modulated signals over outdoor antennas with MER gain of 20 dB to 30 dB which can be measurable at the antenna box. Values between 13 dB and 20 dB are expended for portable receivers with indoor antennas.
- b) Global positioning system instrument measured:
 - i. Test Points on the Google Map (Coordinates of point)
 - ii. Distance from Lusaka DTT antenna
 - iii. Elevation above the sea level

Figure 4.17 (a) and Figure 4.17 (b) show examples of readings displayed on the portable TV test receiver and STB. It was observed that the readings differed slightly between the readings obtained from the portable TV test receiver using standard antenna and STB using ordinary YAGI antenna. Portable TV test receiver showed much higher than the STB readings.



(a) Portable TV test receiver



(b) Set top box

Figure 4.17: Portable TV test receiver and standard STB readings

4.6 Limitation of findings

The research has made an attempt to answer all the research questions despite the fact that the digital migration has been implemented, partially, along the line of rail from Chililabombwe to Livingstone as the first phase implementation process. The second and third phase of DTT implementation were yet to be carried out. Hence, software simulation and signal field strength measurements could not be evaluated for the country but was only limited to the first phase.

The findings of the study revealed that the issue of the STB has not been resolved for many people to appreciate the digital television reception.

4.7 Summary of findings and discussion

It was observed from the findings that the field strength of transmitted signals decreased with distance from the transmitter and varied across individual transmitter locations as shown in Table 4.5. At locations close to a station's transmitter the variation of signal strength across time and location were generally not noticeable. However, as distance increased, the variability of the available signal strength with both location and time decreased gradually. At the edge of transmitter's service area, its signal would be available in some locations more of the time than at others.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter will summarise the study by reviewing the research problem, the theoretical framework, the research questions, the methodology, the findings and final conclusion. Furthermore, the chapter will also assess whether or not the research questions were adequately responded to by the findings. In doing so, the chapter will comment some limitations discovered during the research of the application of Single and Multiple Frequency Networks in view of Zambian topographical terrain which served as a hindrance for the study to arrive at the particular findings. The chapter will also conclude the extent to which the findings evaluated the Zambian DTT footprint, transmission and reception of the digital television signal. The final part of this section of chapter will provide recommendations to overcome some technical challenges of digital television implementation, recommendations to the viewers on equipment to use in order to have a positive impact on digital television universal access, and also recommendations for future studies.

5.1 Adoption of digital television in Zambia

The international telecommunication union (ITU) set a worldwide digital terrestrial transmission migration deadline of 17th June 2015. The international Telecommunication union's position on digital migration was necessitated by the development in telecommunication technologies which enable a more efficient use of radio frequency spectrum, improved picture and audio quality. Previously, broadcasters relied on radio spectrum for TV transmission, however, this had underlying restriction posed by the analogue transmission. Adjacent analogue transmission were found to be subject to interference, forcing the regulatory bodies to leave spaces between channel and only allocate a small percentage of available spectrums for television transmission, to ensure high quality transmission and reception throughout the regions served. All these disadvantages have been surpassed with the arrival of digitization, which gives better clarity, quality of signal, spectrum efficiency and digital dividend.

From the foregoing discussion, it can be concluded that digital television broadcasting when fully implemented will help to improve accessibility, sharp picture quality, good and efficient programming, and so on.

In order to meet the deadline, Zambia, being a member of ITU, aligned its digital switchover plan in line with the Regional Radio Communication Conference of 2006 (RRC06) held in Geneva, the subsequent Geneva 2006 agreement (GE06) of ITU recommendations and finally, the SADC resolution. The study revealed that despite a number of successes provided by the new technology in the broadcast industry across the world, there are, also, some challenges that have continued to affect modern digital television development in Zambia as well. The challenges were alighted in Chapter One and included the following; skilled manpower development, public awareness and campaigns, imposed government regulation, infrastructure development, financial challenges to implement the project urgently and throughout the country, set top box (STB) technical specifications, availability and cost, etc.

It is therefore recommended that care must be taken to ensure that adequate preparation and implementation are made to overcome those challenges before a complete analogue switch off (ASO) is implemented. The findings discovered that financial constrains delayed the commencement of the Phase 1 implementation of the DTT project and consequently, Phase 2 and 3 are yet to be implemented. Therefore, Government must partner with other stockholders towards the actualization of this noble dream throughout the country.

Despite the challenges alluded to by the findings, there are recognizable benefits to stakeholders (broadcasters, regulator and viewers) in Zambia within the DTT ecosystem. It is therefore worth concluding that the idea of digital television broadcasting is a progressive undertaking for all stakeholders since it will help to improve quality programming, reception and content quality, multiple TV channels and more interactive, introduction of value added services, greater spectrum efficiency use, e-programme implementations, etc.

From the findings, many people are still tuning to the analogue transmission during the simulcast period despite the completion of Phase 1 digital television transmission. This is mainly due to lack of STBs on the market, public awareness and campaigns along the line of rail.

5.2 Optimal application of Single and Multiple Frequency Networks in Zambia

The analysis made from all these postulations show that the Zambian geographical terrain is not uniform, as such it is not possible to apply only SFN or MFN across the country because some areas are challenged with severe geographical terrain. For example, the overall simulations results for Phase 1 DTT implementation in Zambia as demonstrated in Figure 4.15 show that Mazabuka, Chisamba and Chibombo along the line of rail, will not be serviced by any of the transmitting stations around the named areas and will remain a technical challenge.

It can be concluded from the simulation results and physical signal field measurement tests that the MFN will provide large coverage areas i.e. Senkobo, Pemba and Kapiri Mposhi because the geographical terrain is fairly flat and high power transmitters have been installed to provide large signal coverage areas. However, it is at the expense of bandwidth serving, that is, 24 MHz bandwidth (8MHz per transmitter) will be occupied and capital expenditure on the power transmitters is high. It can be further deduced that the SFN will provide effective signal field strength coverage in complex geographical terrains in Chilanga, Kafue, Ndola, Chingola and Kitwe. Also SFN will provide spectrum band optimisation and bandwidth serving. From the results, it is concluded that two SFN systems with six digital transmitters, namely, Lusaka-Chilanga-Kafue and Ndola-Kitwe-Chingola SFNs, will occupy 8 MHz each, respectively, and total bandwidth to be occupied will only be 16 MHz for six transmitting stations as compared to 32 MHz for four transmitters in the MFN system. It can be, generally, concluded that for SFN planning and coverage optimisation require adequate understanding of network planning together with detailed geographical terrain, clutter information and an up-to-date transmitter station data base to provide accurate simulation results. The more accurate field strength predictions and the data base, the more reliable are the results. This can be attested by the results obtained through coverage map prediction simulations and the actual field signal field strength measurement that were taken and recorded in Table 4.5.

It is worth noting that SFN systems offer many potential advantages as where enhanced signal coverage is concerned, but to realize the full benefit of these systems, they must be planned and implemented, carefully. Because the network characteristics like synchronisation provides the foundation for proper SFN. Single Frequency Network allows also mixed SFN-MFN operation

within a given geographical area like Chilanga and Kafue, where two or more transmitters carrying the same data and operate on the same frequency.

Factually, it can be deduced that SFN is a better approach in terms of frequency and power efficiency than MFN. On the one hand, the fact that all transmitters employ the same frequency band leads to efficient use of the available bandwidth and mitigates the network planning process. But then, the network gain, i.e. the diversity gain provided by the SFN architecture enriches the overall performance of the broadcasting network, increasing coverage over bigger geographical and complex areas, reducing the power and saving frequency spectrum against analogue or MFN networks.

Unlike, in Multiple Frequency Network scenario where independent frequency and channels can be provided, respectively. In the SFN such cases, the signals from each transmitter needs to be accurately time-aligned, which is done with synchronization information in the T2-MI (modulation interface) stream added by the T2 Gateway at the headend.

Further, it should be observed and concluded from the findings that in SFN, capital expenditure will be reduced because low power transmitters are used and provide enhanced coverage and better signal quality in relatively small area.

In the final evaluation analysis of this research, actual signal field strength measurements were performed at different geographic locations in order to guarantee good reception as indicated in Table 4.5. With the help of these simulation for coverage map predictions and the actual signal field strength measure, it is possible to adjust the transmission parameters of the transmitter system and orientation of transmitting antennas in order to achieve optimal signal coverage. Moreover, viewers can be advised what type of receiving antennas (indoor or outdoor) which can be deployed to provide good signal field strength.

5.3 Signal field strength

From the findings, it can be concluded that in weak signal areas on incline of mountains/hills in river valleys and other shaded locations, both, predicted and actual signal strength measurements, proved insufficient signal strength in areas like Chibombo, Chisamba and Mazabuka as presented in Figure 4.5. These areas are currently, supplied by analogue transmission from Pemba and Kapiri Mposhi analogue transmitting sites, respectively. Areas in the valleys of mountains have to be handled even more thoroughly by SFN like Kafue and Chilanga.

Although the reception of digital signal is, mostly, following the predetermined forecast, some critical locations still need optimisation by adjusting transmission parameters and orientation of radiating antennas. Indoor or outdoor antenna locations have to be positioned free from obstruction and elevated at least above the ground level and mostly on the roof top for outdoor YAGI antennas, or indoor active antennas have to be employed instead of passive rod antennas. Classic weak signal areas, like river valleys or shaded urban sites like Mazabuka, obviously, need gapfillers to improve signal coverage or even allow for reception/service in the area. Test point number 10 in Table 4.5 proves the absence of digital television signal in Mazabuka both from simulation and signal field measurement results, respectively. DTT transmitters at Pemba and Kafue cannot provide DTT signal at Mazabuka because of the geographical position and terrain of the area despite being closer to these transmitting sites.

5.4 Signal footprint in Zambia

Currently, Zambia has only implemented Phase 1 digital migration, Phase 2 and Phase 3 are yet to be done. Hence a complete signal footprint for Zambia could not be evaluated because data for the transmitters, installation positions, frequency network to applied and other technical parameters were yet to be availed by Ministry of Information and Broadcasting Services for provincial and district centres.

However, Phase 1 footprint of the digital migration project is as indicated in figure 4.15. It can be deduced that the line of rail from Chililabombwe to Livingstone is, relatively, covered. However there are some areas that consideration should be made in order to optimise the network. Chibombo and Chisamba will definitely need either gap fillers or change of some parameters and antenna orientation pattern to cover those areas.

From the foregoing discussion, it can be further concluded that digital television broadcasting when fully implemented will help to improve accessibility, sharp picture quality, good and efficient programming, utilisation of digital dividends and so on. However, there are also a number of challenges such as technical know-how, inadequate skilled labour, lack of income and incessant government regulations. It is recommended, therefore, that government and other stakeholders should ensure that the problems identified above should be properly handled before the analogue switch off of transmission.

5.5 Recommendation for gapfillers

Gapfiller transmitters are fed off-air from mainly a nearby transmitter to provide small SFN-MFN network for a particular area like Mazabuka and Chibombo. Therefore, it can be recommended that gapfillers (fill-in lower power) transmitters should be installed in Mazabuka and Chibombo or Chisamba in order to optimise signal coverage for Phase 1 DTT implementation. It can be further deduced that gapfiller transmitters are cost effective and frequency efficient way to improve coverage in particular areas that can have signal reception challenges. Gapfillers require, sufficiently, strong input signal received from the main transmitter nearby or via satellite fed or microwave or cable link. It should be taken into consideration that gapfillers/repeaters in Frequency Networks have to be installed thoroughly to avoid instability caused by feedback. The radiated power of a gapfiller transmitter is low and often have a directional antenna to service a specific area. So for Chibombo and Mazabuka, this should apply.

Finally, in the event that gapfillers are unable to service some areas completely, then Direct-To-Home satellite receiving equipment can be used to feed vulnerable areas.

5.6 Summary of the conclusion

In summary, it is necessary to do signal coverage predictions and actual signal field test for each terrestrial television transmitting station or a group of such stations. Generally, signal field strength test are crucial because they determine either to increase the transmitter powers or provide a number of gapfiller transmitters in order to guarantee coverage to the last few percent of the worst-served areas.

Digital television transmission is characterized by a rapid transition rather than analogue transmission from near perfect reception to no reception at all and thus, it becomes critical to define which areas are going to be covered and which are not. The evaluation of signal strength, SFN and MFN application in the DTT implementation in Zambia is significant in the determination of the entire project outcome.

5.7 Future works

Future works will require to perform overall simulation of all transmission sites in the entire country and signal field strength measurement testing so that optimisation of signal coverage can

be assessed and further, making recommendations to the Government or contractor for areas that will, seemingly, not have signal field strength coverage for considerations.

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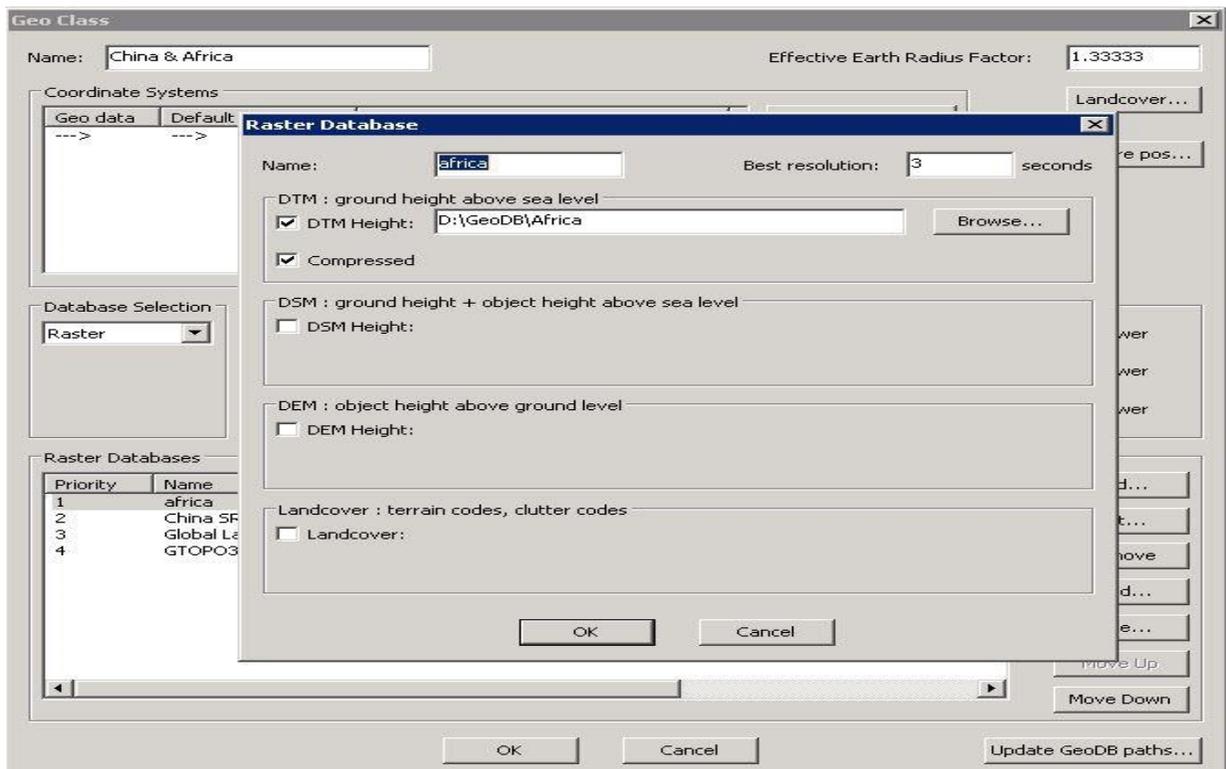
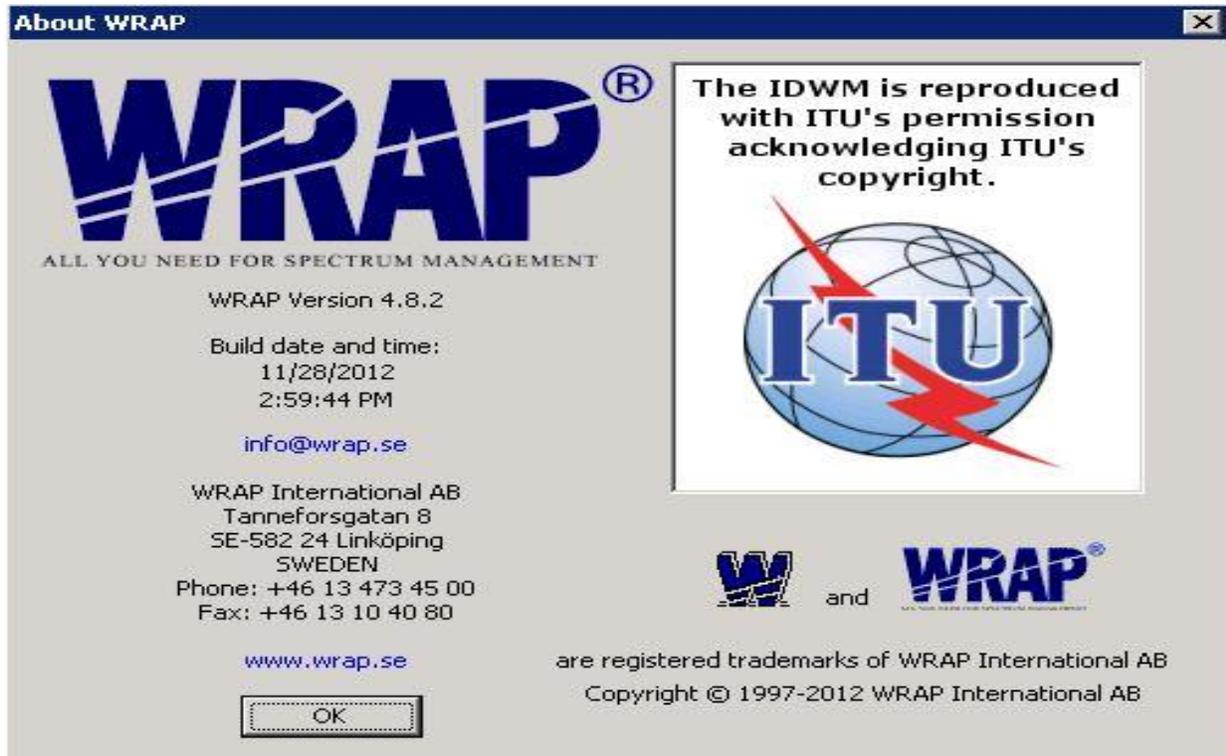
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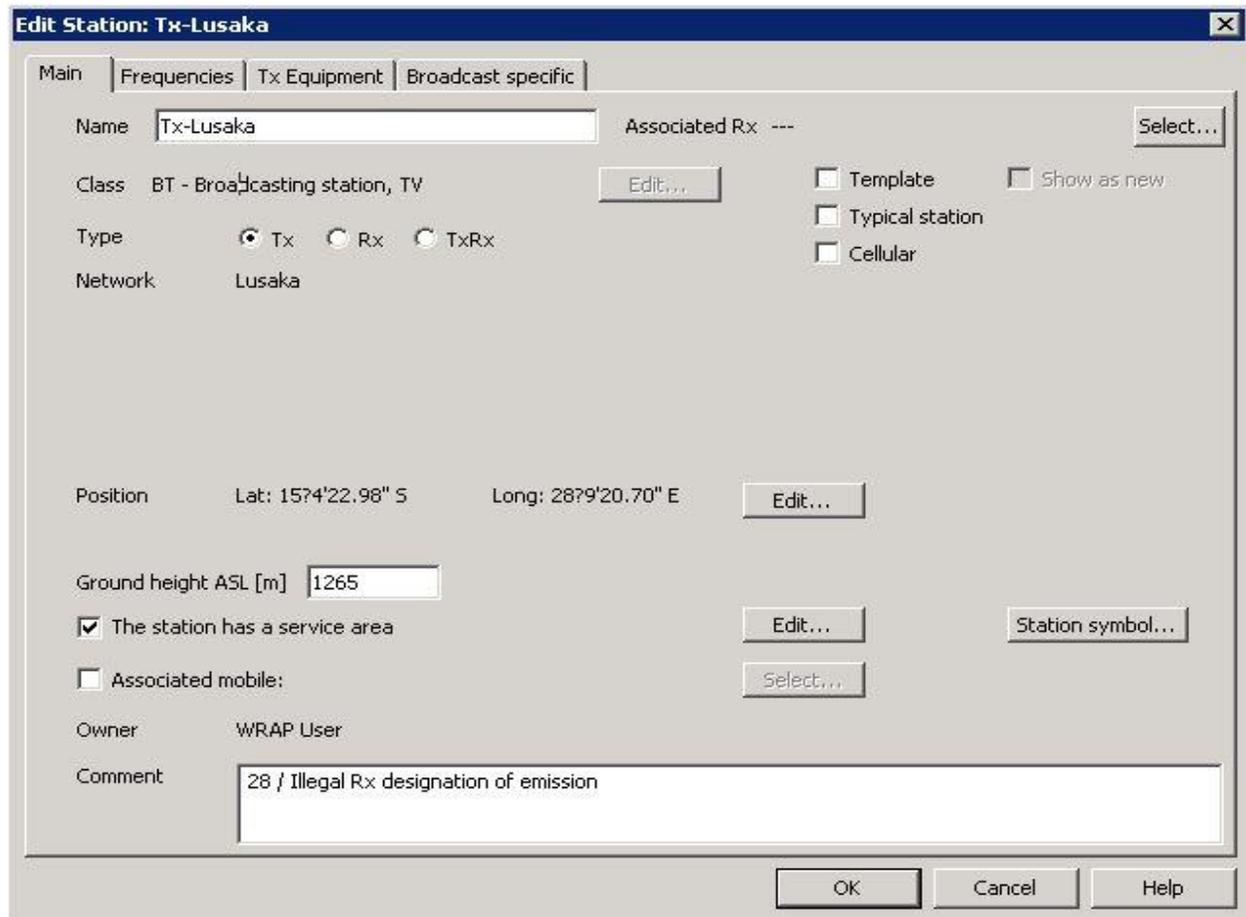
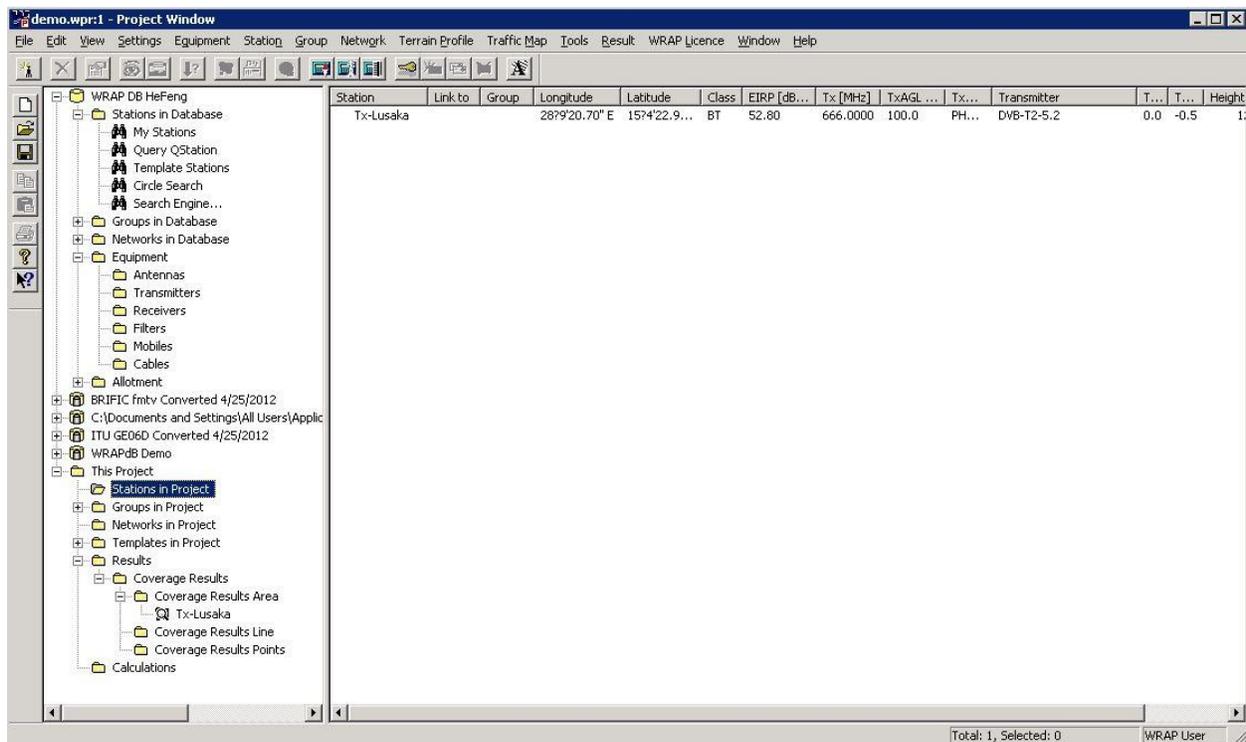
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APPENDIX A

Coverage map prediction simulation





Edit Result [X]

Information | Presentation | Coverage Information

Type of calculation: Field Strength dB μ /m, 80.0 % Probability Calculation direction: Downlink
 Date: 1/23/2014 11:45:27 AM
 Execution time: 00:00:20

Statistics					
Min	-121.2	5%	1.2	90%	75.5
Max	115.0	10%	13.7	95%	83.6
Mean	46.4	50%	49.4		

Station: Tx-Lusaka [Details...]
 Propagation model: Detvag-90/FOI [Details...]
 Interferer model: --- [Details...]

Resolution [m]: 503
 Terrain Height Res [m]: 89

Description:
 Tx-Lusaka

[OK] [Cancel] [Apply] [Help]

Edit Station: Tx-Lusaka [X]

Main | Frequencies | Tx Equipment | Broadcast specific

Transmitter: DVB-T2-5.2 [Select...] [Edit...] [Remove]

Edit Transmitter [X]

Main | Frequency Characteristics | Miscellaneous | Digital Modulation | Calculations

Name: DVB-T2-5.2

Frequency: 474 To 860 MHz

Modulation type: Digital Analog

Occupied bandwidth [kHz]: 8000 Power [dBW]: 37.2

Necessary bandwidth [kHz]: 7800

Class of emission: D7W

Owner: WRAP User

Comment:

[OK] [Cancel] [Apply] [Help]

Edit Station: Tx-Lusaka

Main | **Frequencies** | Tx Equipment | Broadcast specific

Frequency: Single Frequency Net [v] From allotment...

Frequencies

Calc./Hailing Fq	Tx [MHz]	Rx [MHz]	Channel	Offset	Usage	Comment	Start Dat
<input checked="" type="checkbox"/>	666.00000	0.00000		0			

Delete

OK Cancel Help

Edit Transmitter

Main | Frequency Characteristics | Miscellaneous | **Digital Modulation** | Calculations

Modulation: QAM [v]

Modulation factor: 256

Data rate [kbit/s]: 38000

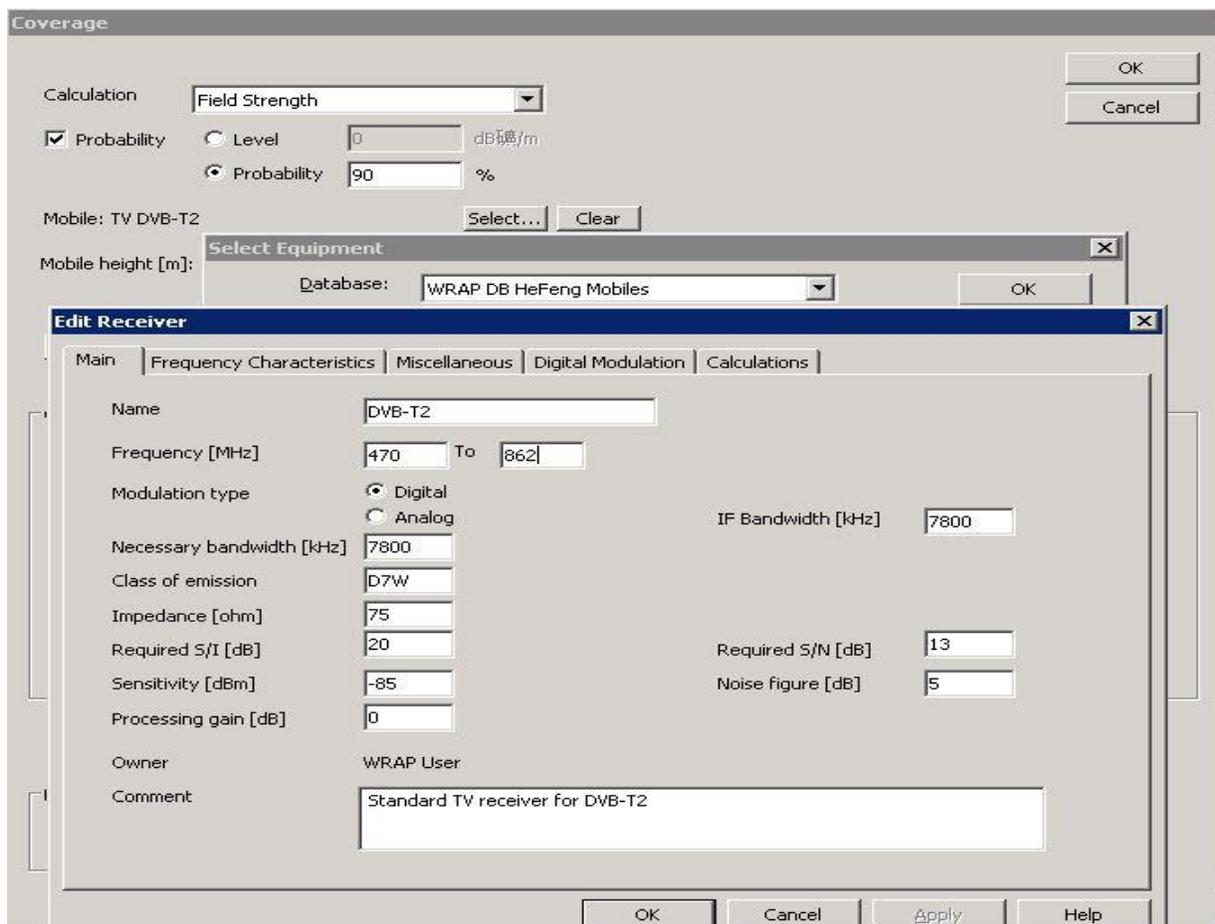
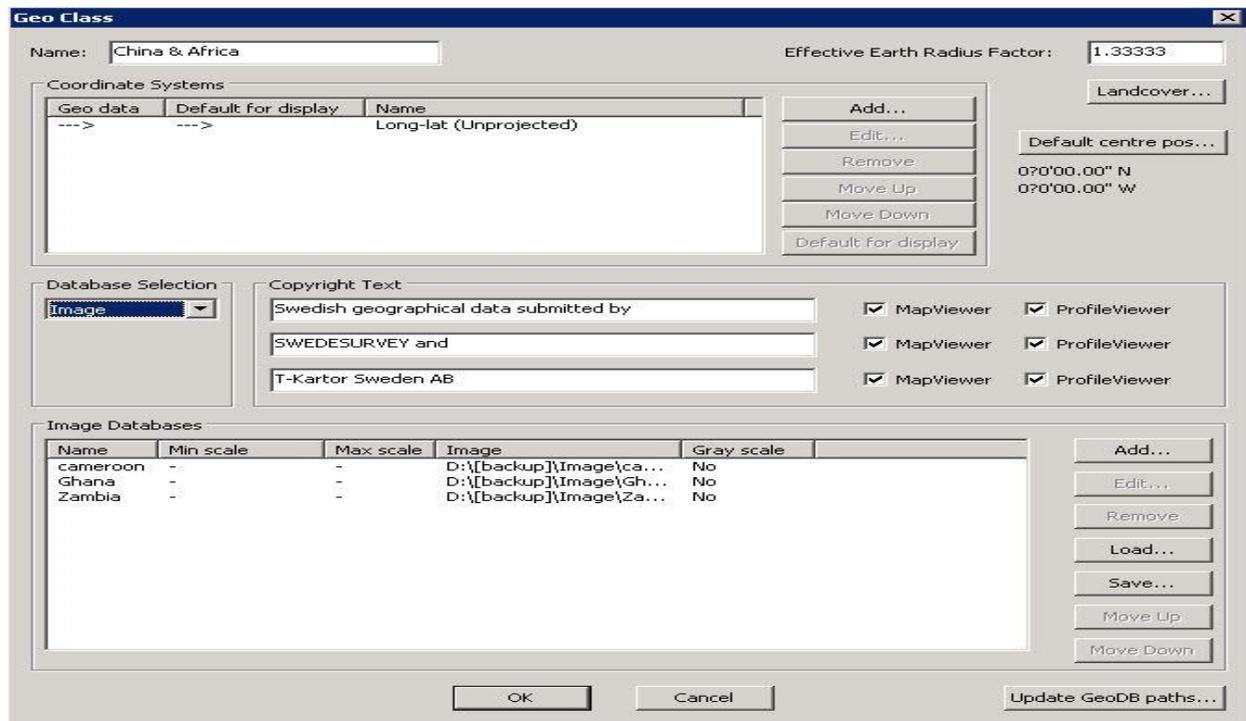
OFDM Area of Application: DVB-T2 [v]

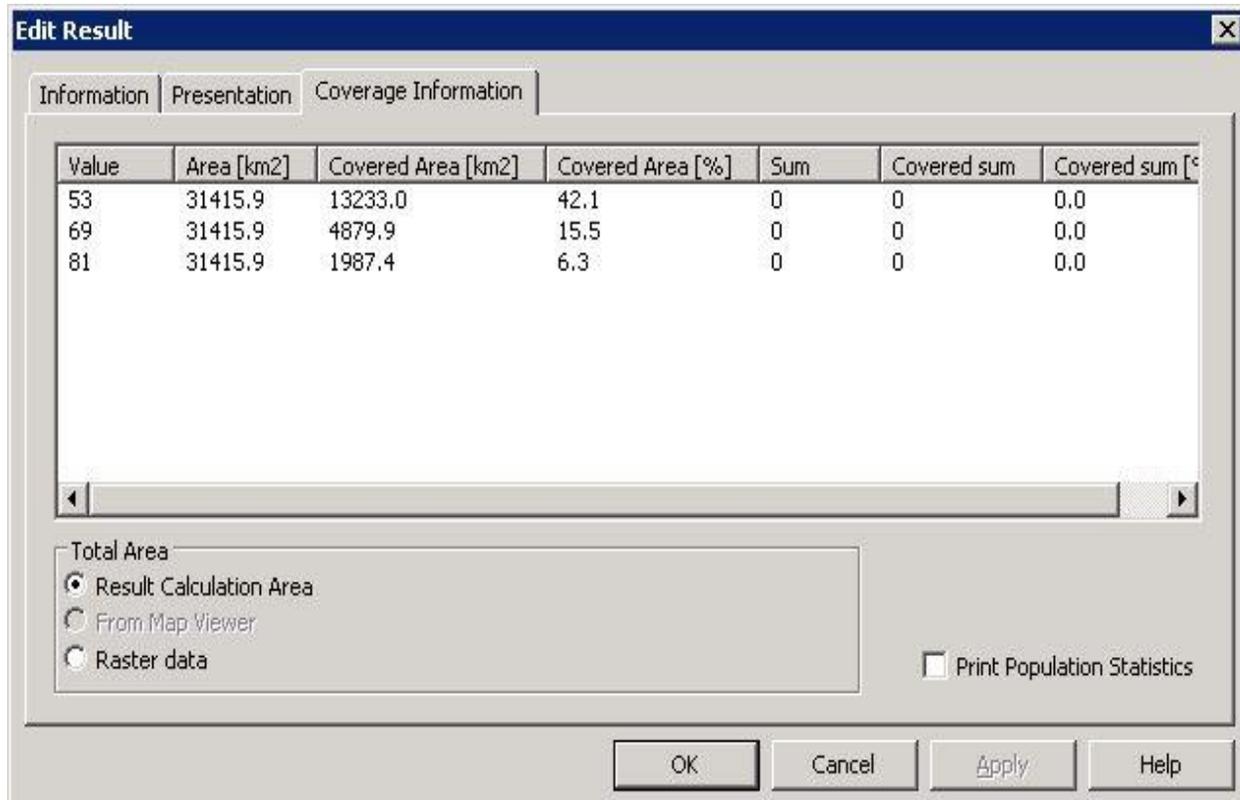
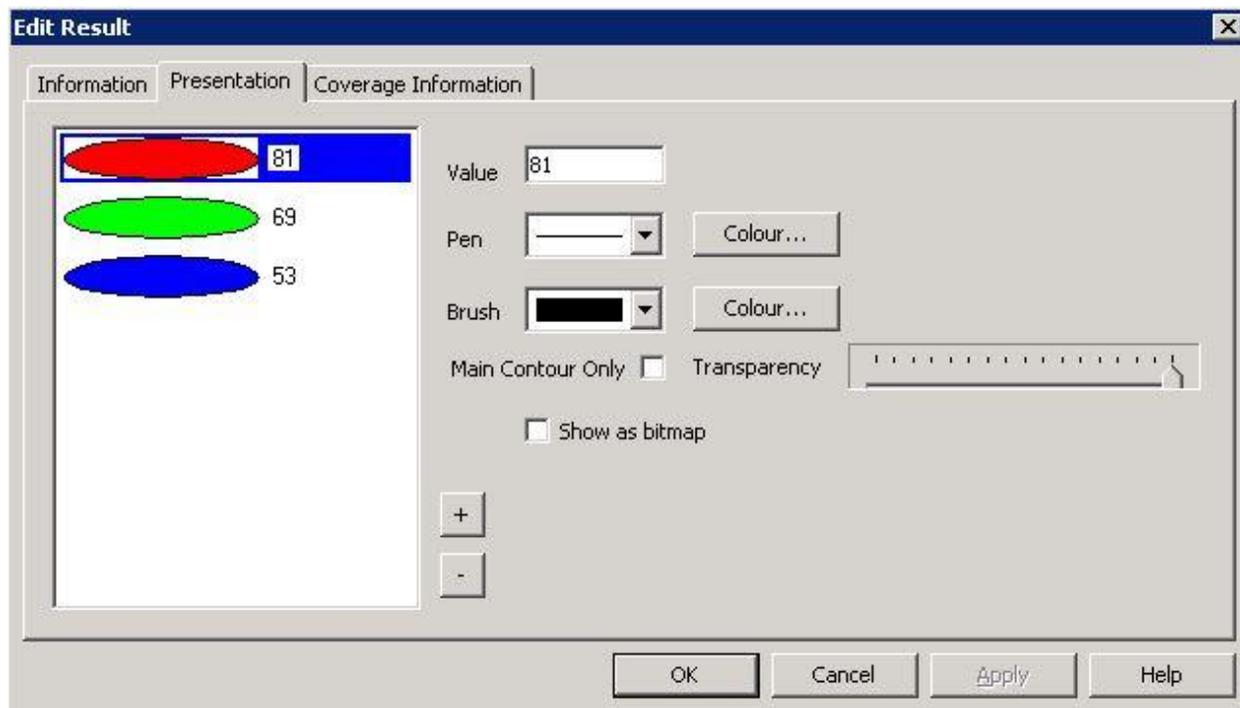
OFDM Parameters

Mode: 32k Mode [v] Tg/Tu: 1/32 [v] Code Rate: 2/3 [v] PP6 [v]

Carriers: 27265 Tg [μs]: 112 Tu [μs]: 3584 Max distance [km]: 33.6

OK Cancel Apply Help





APPENDIX 2

Transmitting antenna simulation

Edit Station: Tx-Lusaka

Main | Frequencies | **Tx Equipment** | Broadcast specific

Transmitter: DVB-T2-5.2 [Select...] [Edit...] [Remove]

Designation of emission: 7M80D7W Power [dBW]: 37.2

Antenna	EIRP [dBW]	Height AGL [m]	Azimuth [deg]	Tilt [deg]
PHP-8*4	52.8	100	0	-0.5

[Add...] [Edit...] [Remove]

Beamwidth [deg]: 0 Gain [dBi]: 16.05 Polarisation: Horizontal linear

Filter: [Select...]

Cable: [Select...] [Edit...] [Remove]

Cable length [m]: 0 Azimuth [deg]: 0

EIRP [dBW]: 52.8 [Calculate...] Antenna tilt [deg]: -0.5

Height AGL [m]: 100 Duty cycle [%]: 100

Vision-to-sound ratio [dB]: 10

[OK] [Cancel] [Help]

Edit Station: Tx-Lusaka

Main | Frequencies | Tx Equipment | **Broadcast specific**

Effective Antenna Height

Azimuth [deg]: 0 [->]

Effective antenna height [m]: 0 [-<]

[Calculate]

Azimuth	Height

Broadcast Television

TV System: DVB-T2

Time Delay (+/- 1000 µs): 0 [µs]

[OK] [Cancel] [Help]

Edit Station: Tx-Lusaka

Main | Frequencies | Tx Equipment | Broadcast specific

Transmitter: DVB-T2-5.2 [Select...] [Edit...] [Remove]

Designation of emission: 7M80D7W Power [dBW]: 37.2

Antenna	EIRP [dBW]	Height AGL [m]	Azimuth [deg]	Tilt [deg]	
PHP-8*4	52.8	100	0	-0.5	[Add...]
					[Edit...]
					[Remove]

Beamwidth [deg]: 0 Gain [dBi]: 16.05 Polarisation: Horizontal linear

Filter: [Select...]

Cable: [Select...] [Edit...] [Remove]

Cable length [m]: 0 Azimuth [deg]: 0

EIRP [dBW]: 52.8 [Calculate...] Antenna tilt [deg]: -0.5

Height AGL [m]: 100 Duty cycle [%]: 100

Vision-to-sound ratio [dB]: 10

[OK] [Cancel] [Help]

