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CONTENTS

Preliminary performance evaluation and verification of digital terrestrial television signal propagation

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Abstract. This article presents the computer simulation and field test measurement results on Channel 29 for the preliminary performance evaluation and verification of the newly-installed Lesotho digital terrestrial television network based on DVB-T2 standard following the guidelines and techniques specified by the ITU-R BT.2035-2. It evaluates, at predetermined outdoor locations for fixed and mobile reception, parameters such as received signal strength, signal quality, bit-error rate (BER) and threshold-of-visibility (ToV) together with TV signal decoding (observation of screen artefacts) for quasi error-free reception. The results indicate that at over 97% of the test sites/points at the university town of Roma, the main Berea Plateau transmitter from the capital city (Maseru) broadcasts digital television service with enough signal level and quality to be properly decoded. The measured signal strength threshold ranges above -50 dBm for good reception, -64 dBm to -50 dBm for acceptable reception and -69 dBm to -64 dBm for poor reception. With the noise floor at about -73 dBm, the minimum required C/N of around 23 dB for good reception and about 4 dB for ToV have been recorded. The relative values of minimum required respective signal strength and signal quality for ToV obtained from the set-top box are 33% and 18% for stationary reception, while they give 37% and 20% for mobile reception.

Keywords: DTT performance, mobile reception, signal strength, stationary reception, threshold of visibility.

1. Introduction

The television (TV) broadcasting industry in Lesotho has been dominated by the giant South African-based MultiChoice with its digital satellite service under the DSTv brand. The local public service broadcaster, Lesotho National Broadcasting Services (LNBS), operates a single analogue terrestrial TV channel that broadcasts live for only 7 hours per day, and it is also replicated on DSTv Channel 292. From 2006, with the agreed mandate from the International Telecommunications Union (ITU) for countries in Region 1 to migrate to digital terrestrial TV (DTT) broadcasting by 17 June 2015, efforts were put in motion for the country to be ready for analogue switch-off by the international deadline, though with little success due to various migration challenges [1]. However, since then, there has been demonstrable progress, especially in the building of transmission infrastructure based on the second-generation Digital Video Broadcasting – Terrestrial (DVB-T2) standard at different locations around the country as indicated on Fig. 1. Most of the transmitter locations were already in use for terrestrial analog FM radio broadcasting and are able to communicate via microwave links.

As evidenced by the topographical map of Fig. 1, about 70% of the country's terrain is characterized by rugged mountains and elevations in excess of 1400 m, presenting a challenge for optimal location of broadcasting transmitters. The LNBS's optimized DTT network configuration comprises 20 transmitter sites to cover the country's approximately 30,355 km2 area, which is completely surrounded by South Africa. The main transmitter station for coverage provision in the capital city Maseru is called 'Berea Plateau', located in the western lowlands at an elevation of 1829 m. At the time of writing, only the main Berea Plateau transmitter station was operating in Channel 29 (538 MHz) under test conditions with set-top boxes (STBs) from Reutech (South Africa) and StarTimes (China).

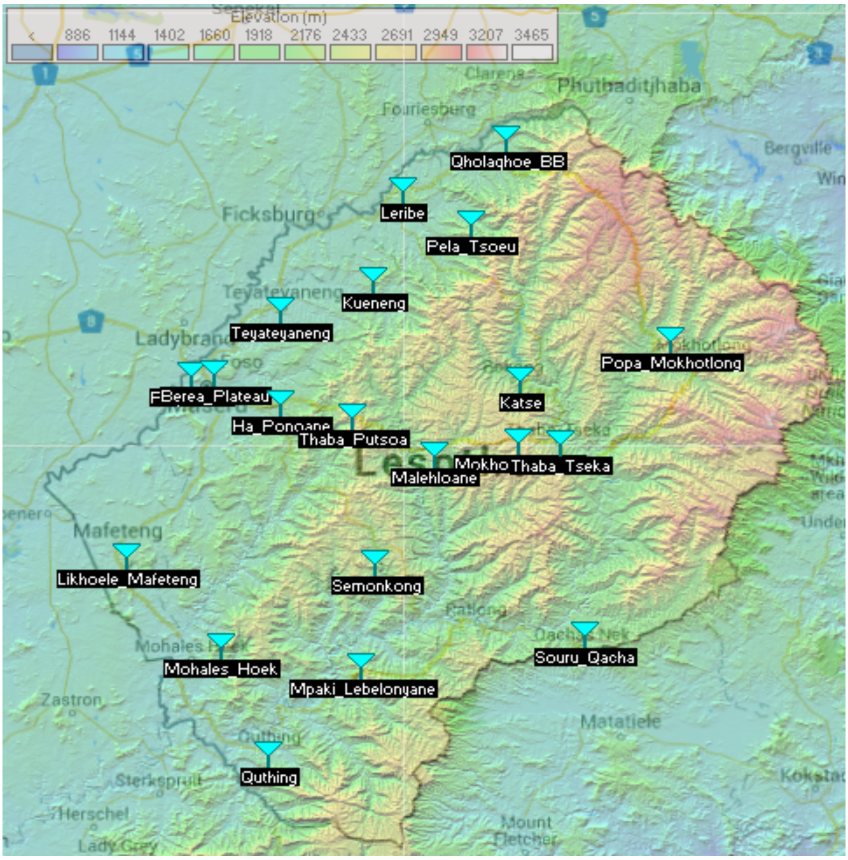


Fig. 9. Topographical map of Lesotho showing locations of newly-built DTT transmitter stations

The LNBS DTT network topology is shown in Figure 2, adapted on the French Eutelsat geo-stationary satellite link as the primary distribution network and the 20 terrestrial transmitter stations forming the secondary distribution network, configured as a multiple frequency network (MFN) consisting of individual transmitters with each transmitter on a different frequency. The head-end system and uplink satellite dish are located at the main transmitter site at Berea Plateau. The DTT signal is converted to DVB-S2 and encrypted for uplink and the resulting transport stream is fed into the primary distribution network by means of a microwave satellite feed at 8° West for easy implementation of its point to multipoint distribution [2]. The downlink DTT signal from the satellite is then decrypted and redistributed as DVB-T2 on a free-to-air (FTA) basis by the terrestrial transmitter stations scattered around the country as in Figure 1 to cover various service areas.

Experience from early adopters has shown that first-time operation of new DTT broadcasting network, with limited time for planning and extensive testing due to accelerated digital switchover, can be technically challenging [3]. This can lead to reception problems at shadowed areas without coverage, known as black spots, due to an uneven terrain and non-optimal tower erection. Hence this study aims to measure actual service versus predicted coverage by modelling the DTT network for Lesotho and performing the first verification of area coverage for correct decoding of digital TV signal against the basic parameters stated in the ITU-R BT.2035-2 guidelines and techniques [4]. It employs useful comparison of computer simulated predictions using Radio Mobile software [5-7] with practical field strength measurements in validating network performance. This is followed by the determination of minimum signal strength and carrier-to-noise ratio (C/N) required to attain quasi-error free (QEF) reception under real propagation conditions. As an indication of proper digital signal decoding, coverage evaluation with the observation of the image on the TV screen is performed in predetermined sites.

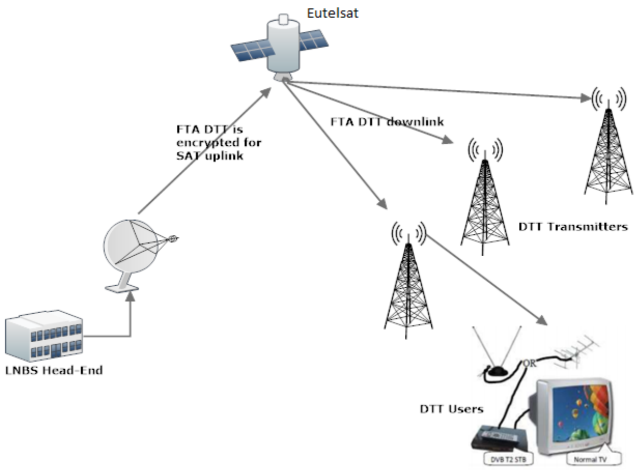


Fig. 10**.** LNBS DTT network topology.

The results of the study, if replicated throughout the country, will help identify problem sites within the network coverage area or its peripheries where DTT signal is poorly available, and act as aid to confirm DTT broadcasting coverage requirements, and assist in future planning to maximize coverage and service quality. The accurate knowledge of the quality of DTT coverage to be provided will be key to the implementation of digital television services and give credibility to the service provider before total analogue switch-off.

2. Review of DTT Network Simulations and Measurements

The transmitter network structure for coverage planning involves optimizing the locations of transmitters and gap-fillers in regions where the service is poor. Two reception conditions, fixed (or stationary) and portable (or mobile) are usually considered in DTT broadcasting [11]. Receiver antenna heights range around 10 m and 3 m for fixed reception and 1.5 m for portable reception with directional and omni-directional radiation patterns, respectively [10, 13]. As a rule of thumb, if the required C/N is attained 99% of time, the location is deemed to be covered [11]. Furthermore, coverage of a small area, typically 100 m x 100 m, is classified as "good" if at least 95% of receiving locations within it are covered, or "acceptable" if at least 70% of locations within it are covered [14].

Due to continuing co-existence with analogue services in many regions which failed to meet the ITU deadline, tighter margins on the signal strength and interference are placed on digital broadcasting services and thus, they require higher prediction accuracy than analogue networks [15]. Moreover, picture quality deteriorates sharply over a very small range of signal levels and thus digital television service coverage is characterized by a very rapid transition from near-perfect reception to no-reception at all [14]. As such, various radio-frequency modeling and simulation software packages are available for use in predicting and analyzing the global coverage probability within a target service area. In this study, the Radio Mobile [5, 7] freeware radio propagation simulation program is utilized to model the Lesotho DTT network and allow analytical study of simulated reception conditions to be made.

The models for propagation prediction can be classified as semi-empirical and fully deterministic with varying requirements for initial set-up and provided accuracy [15]. Radio Mobile, which can be classified as deterministic, is based on the Longley Rice Irregular Terrain propagation model and uses high-resolution topographical data from the Shuttle Radar Topography Mission (SRTM) elevation maps to take into account the actual terrain of the area being simulated [6, 7]. It enables merging of elevation contours and roads with maps and allows specification of crucial network information such as location of transmitter stations (units), units' frequencies, transmit power, height, antenna gain, receiver sensitivity and feeder losses [5]. Path profiles with Fresnel zones and signal parameters for radio links between units can be examined, together with signal coverage patterns from individual or multiple transmitter units showing predicted receive signal levels.

Following computer simulation predictions, field test measurements and data collection (coverage, service, modes and channel characteristics) are usually undertaken with the view to ascertain the actual service and be able to improve system performance [4]. Due to local clutter effects (buildings, trees and other obstructions), the reception environment for practical measurements is usually classified in terms of urban, suburban or rural, depending on various characteristics such as densely-populated buildings with high-rise structures, disperse buildings or sparsely-populated structures [4]. Various test parameters for quasi-error free reception or correct TV signal decoding for digital terrestrial television have been measured in several places. The test parameters (and their typical measured values in suburban areas) include signal spectrum, signal or carrier power (dBm), signal field strength (above 50 dBμV/m for stationary reception and above 73 dBμV/m for portable reception), receiver equivalent noise floor (-73 dBm), carrier-to-noise ratio (C/N > 20 dB), bit error rate (BER < 2x10-4 after Viterbi decoder), latitude/longitude and TV set image [10, 12, 14, 16, 17].

3. Simulated LNBS Network Performance

The LNBS's DTT network is simulated using Radio Mobile by first producing the elevation map of Lesotho centred at 29°37′24.0″S, 28°12′16.0″E with 270 km height and 514 x 514 pixels to cover the entire country. An Internet GoogleMap roadmap is merged with the elevation map and the 20 transmitter units are defined to produce the map of Figure 1. The main transmitter station at Berea Plateau, the gap-filler at Ponoane (Roma) and a modeled portable unit with the parameters shown in Table 1 are used for simulation and illustration purposes.

A. Simulated Path Profiles

The Radio Link toolbar is used to examine the simulated path ground profiles and link budget analysis between the main transmitter and the modelled portable unit placed 22 km away at the main entrance to the National University of Lesotho (NUL) Roma campus as demonstrated by Figure 3. The green colour on ground path indicates that the signal level at the receiver is above the minimum margin required for reception. These settings are made relative to the receiver sensitivity, with an intermediate band of signal levels being shown as yellow for ±3 dB, >3 dB as green, and <-3 dB showing red [6]. The figure further demonstrates information regarding the terrain elevation difference, minimum clearance, location of the obstruction giving the worst Fresnel clearance, distance between the units, propagation mode, total propagation loss, field strength, signal level at the receiver and attained link margin.

Table 1. The operating parameters used to define main Transmitter, Gap-Filter and Portable Units

Parameters	Berea Plateau (Main Unit-Maseru)	Ponoane/Roma (Gap-filler)	Portable Unit
Location	29°19′50.8″S, 27°32′25.2″E	29°25′07.3″S, 27°44′35.9″E	29°27′05.0″S, 27°43′13.5″E
Frequency (MHz)	470 – 862	470 – 862	470 – 862
Channel Frequency	29 (538 MHz)	45 (666 MHz)	-
Transmit Power (W)	5000	600	1
Antenna	Omni	Omni	Omni
Antenna Gain (dB)	12.3	7	2
Antenna Height (m) agl	200	30	1.8
Receiver threshold (μV)	1.0	0.5	0.5
Line loss (dB)	1.0	0.5	0

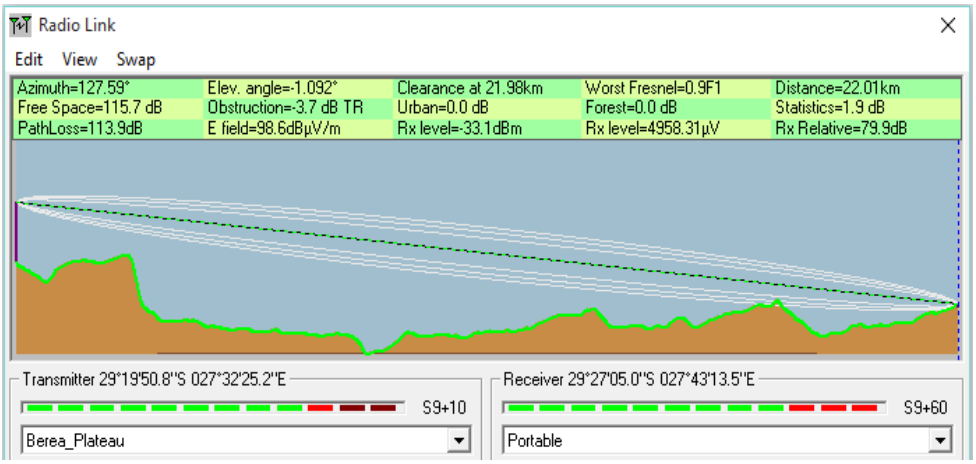


Fig. 11. Simulated path profile between the main transmitter unit and the portable unit.

B. Simulated Coverage Plots

The simulated transmitter coverage plots from Radio Mobile software can be exported to Google Earth to explore the predicted coverage in a three-dimensional (3D) environment. Coverage plots from individual transmitter stations around the country can be aggregated to predict the national DTT signal coverage. For instance, the simulated national coverage map combining all 20 transmitters installed by LNBS is given in Fig. 4. It can be seen that signal coverage is more uniform and strong (red colour) in the western densely-populated lowlands (Butha-Buthe to Maseru to Mohale's Hoek) than in the central and eastern sparsely-populated highlands.

A zoomed-in view of the signal coverage plot for the university town of Roma valley is shown in Fig. 5, depicting TV signal strength distribution from the main Berea Plateau transmitter station. The highlighted spots with circles indicate areas where the signal strength is relatively low, leading to potential coverage gaps with poor signal reception from the main transmitter, especially around the steep hills and the nearby Liphiring river where the valley is deeper. However, a gap-filler transmitter station at the nearby

Ponoane Hill has been installed to provide signal coverage to these spots that are not properly covered by the main transmitter as illustrated in Fig. 6.

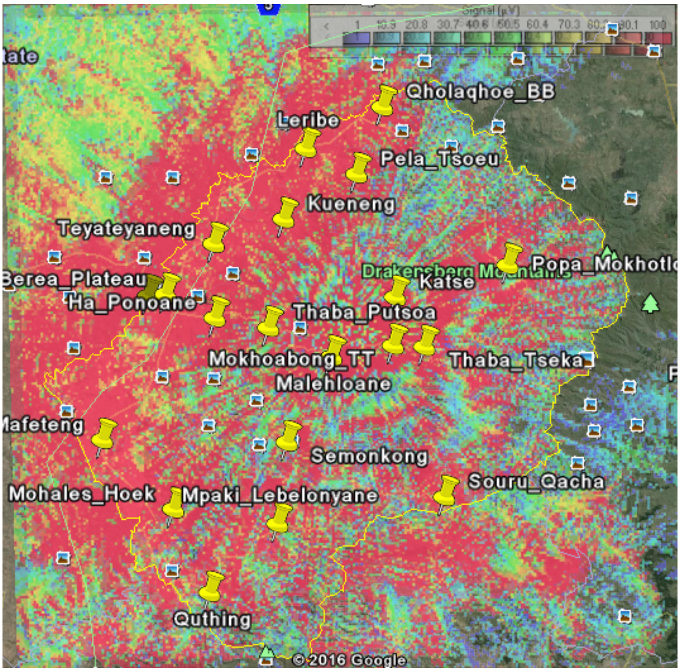


Fig. 4. Simulated Lesotho DTT signal coverage map.

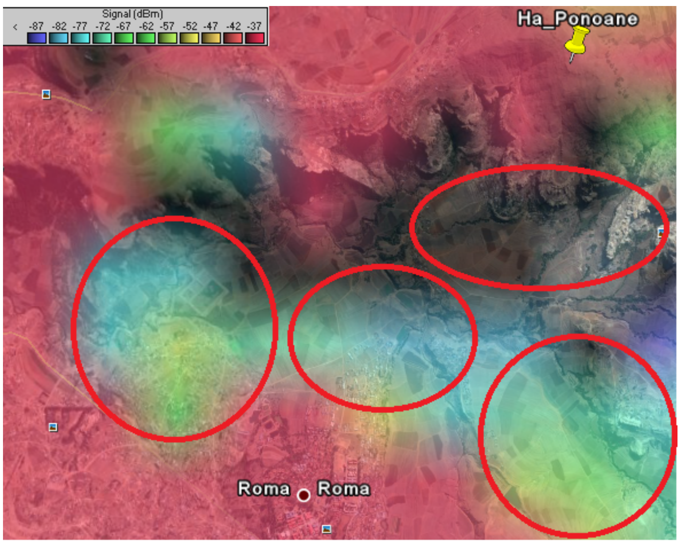


Fig. 5. Simulated coverage plot of the university town of Roma from the Berea Plateau transmitter.

C. Simulated Route Reception

The Radio Mobile software is also able to simulate portable signal reception for demonstration of mobile TV reception. For illustrative purposes, a route from Maseru via Thetsane Industrial Area to Roma is simulated as shown in Fig. 7 (a). With Berea Plateau as the transmitter, Fig. 7 (a) shows that the simulated DTT signal reception varies along the route as indicated by the highlighted areas, becoming smaller (red) around Ha Tsolo and the Roma valley areas. An enlarged view of the simulated poor mobile TV signal reception (below -70 dBm) from Berea Plateau around the first spot at Ha Tsolo is shown in Fig. 7 (b), caused by the nearby obstructing Qoaling Hill towards the right. However, there are gap-fillers at Ratjomose and Ponoane to solve the respective coverage problems of Ha Tsolo and Roma with mobile reception. The improved reception at Ha Tsolo (around -25 dBm) from the Ratjomose gap-filler is illustrated in Fig. 8.

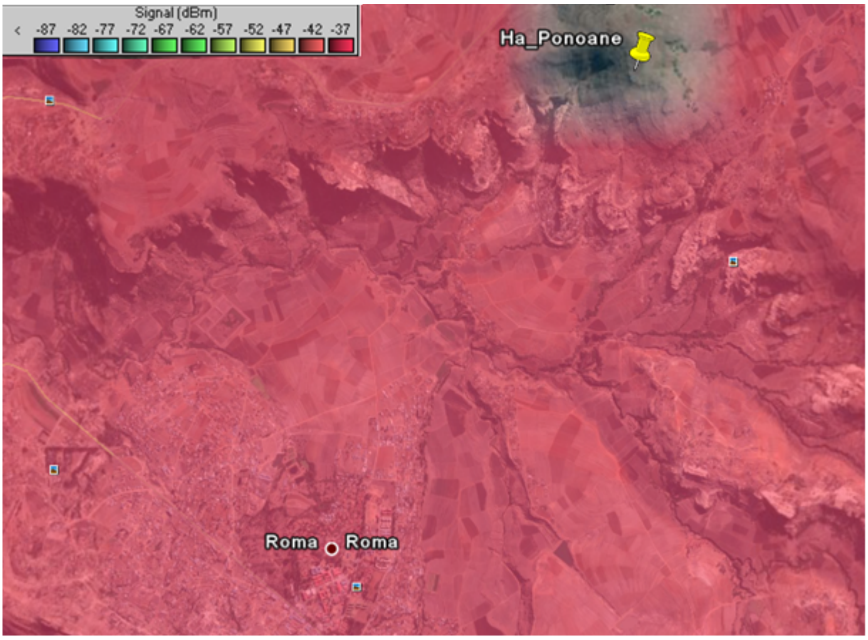


Fig. 6. Simulated coverage plot of the Roma valley from the Ponoane gap-filler transmitter station

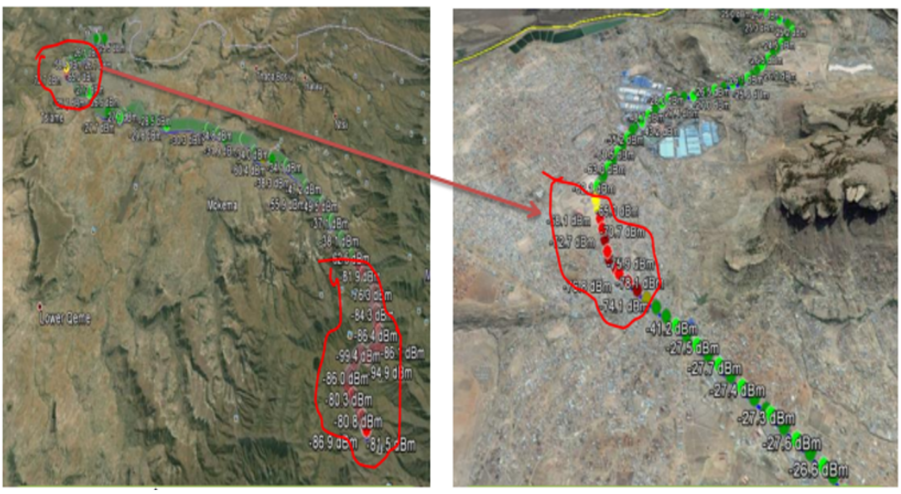


Fig. 7. (a) Simulated mobile route reception from Maseru to Roma (left); (b) The enlarged simulated poor DTT signal reception at Ha Tsolo from the main transmitter (right)

Fig. 8. Simulated improved DTT mobile signal reception at Ha Tsolo from the Ratjomose gap-filler

4. Signal Measurements and Analytical Evaluation

Field data acquisition to evaluate the network performance was carried out with a mobile measurement system set-up as indicated in Fig. 9, following the ITU-R BT.2035-2 guidelines and techniques [4]. The actual measurement system, which is mounted on a vehicle, consisted of a retractable antenna mast, 8-element grid mesh TV antenna, splitter, StarTimes Gemini+ set-top box, RIGOL DSA1030A spectrum analyzer, TV set, GPS receiver and laptop. The power for the equipment was provided by a 350W inverter connected to the van's 12-V cigarette lighter. The antenna mast is extendable to lift the antenna to 3m above ground level for stationary reception or 1.5m for mobile reception.

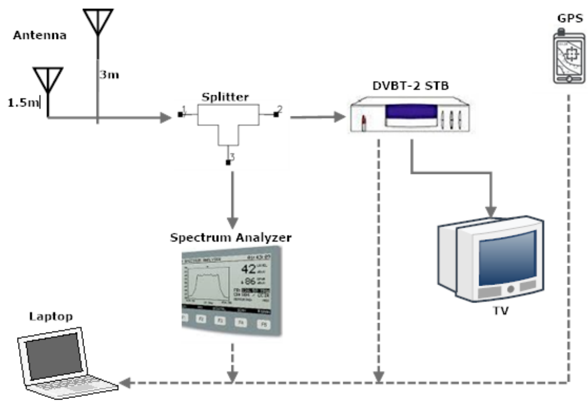
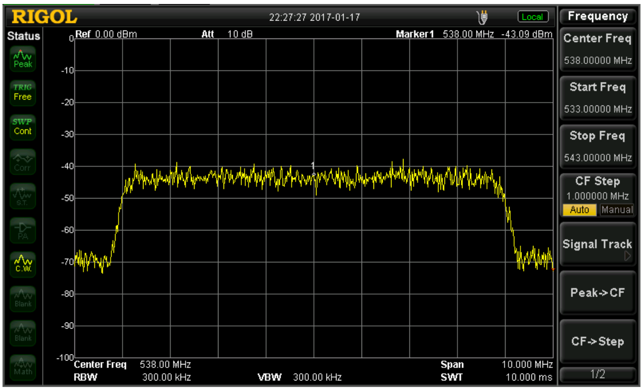
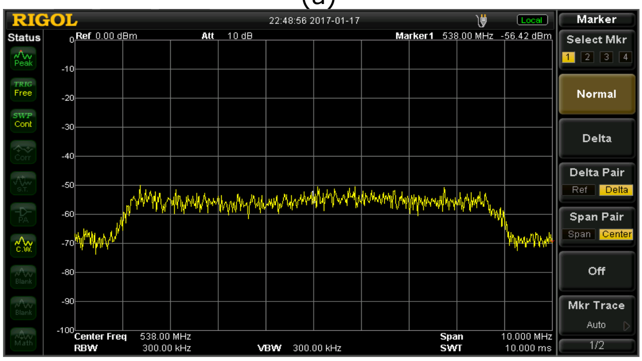


Fig. 9. Measurement setup for DTT signal capturing and analysis.

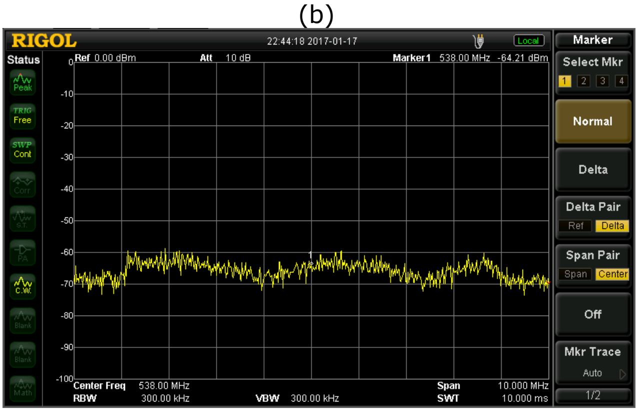
The spectrum analyzer captures and stores details of the signal spectrum, field strength and power received. Observation of the video on the TV screen from the connected STB is used for visual monitoring with the signal classified as either good (near perfect picture) or poor (no picture). The STB further provides measurements of signal strength and signal quality in percentages and BER that are displayable on the TV screen. The minimum values of these parameters (signal strength, signal quality and BER) needed for quasi-error free reception of signal are termed the threshold-of-visibility (ToV).



(a)



(b)



(c)

Fig. 10. Recorded narrow-band (10 MHz) displays of DTT signal spectrum at the selected test points for: (a) good reception, (b) acceptable reception and (c) poor reception

A. Measured DTTB Signal Analysis

The measured signal analysis was undertaken using the obtained signal strength or level, BER, and determination of C/N ratio. At various test points, the signal level and quality was high enough (> -53 dBm) for good quality video reception. At some test points, the signal level was lower than -64 dBm and not good enough for proper decoding of the video. Figure 10 illustrates the narrow-band displays captured from the spectrum analyzer for good, acceptable and poor reception based on the observation of the image on the TV screen and benchmarked with operating parameters in Table II. Another important system parameter measured is the minimum C/N required for QEF reception. At each test point, this parameter is determined by varying the attenuation on the received DTT signal until its strength reaches (ToV), i.e. it is low enough to be considered equal to the set-top box decoder noise floor (-73 dBm) and the picture is lost on the TV/laptop screen. The required minimum C/N averaged around 23 dB.

B. Stationary Reception Results

Two sample areas have been chosen for investigating coverage probabilities from the main transmitter at Berea Plateau relative to the simulated coverage plot of the Roma valley shown in Figure 5. The first area has 26 test points at 100 m intervals within the university campus (see Figure 11) and the second one has 35 tests points at 500 m intervals for villages around the university campus (see Figure 13). The test points have been selected to sample areas with good and poor coverage as predicted by the simulation of Figure 5. The test points are also classified as suburban with disperse buildings where the receiving antenna is mounted at roof top level (3 m). It should be noted that only the main Berea Plateau transmitter was working under test conditions during the study period.

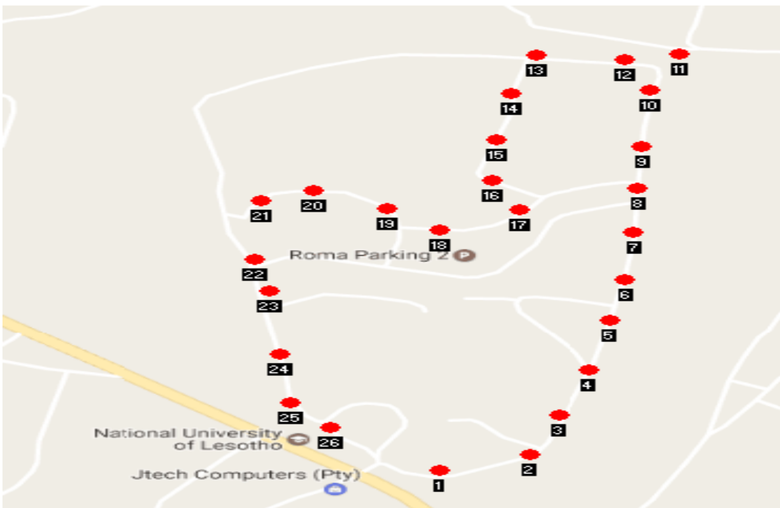


Fig. 11. DTT signal reception test points within university campus.

The measured signal properties for stationary reception test points within the university campus at Roma and for villages around the campus are illustrated in Figure 12 and Figure 14, respectively. The signal strength (%) and signal quality (%) have been captured from the STB readings while the signal power (dBm) was recorded by the spectrum analyzer. For the stationary reception results, the ToV was maintained when the signal strength was 33% or higher and the signal quality was 18% or higher from the STB, with the signal power greater than -70 dBm. Hence for the 61 test points recorded, only 2 points (3%) reached 18% signal quality with – 70 dBm signal power, resulting in poor reception.

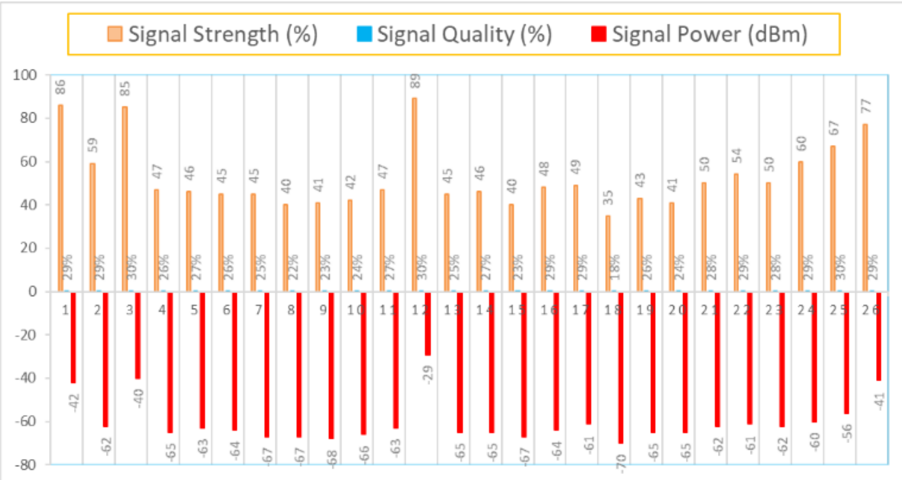


Fig. 12. Measured signal properties at test points within university campus.

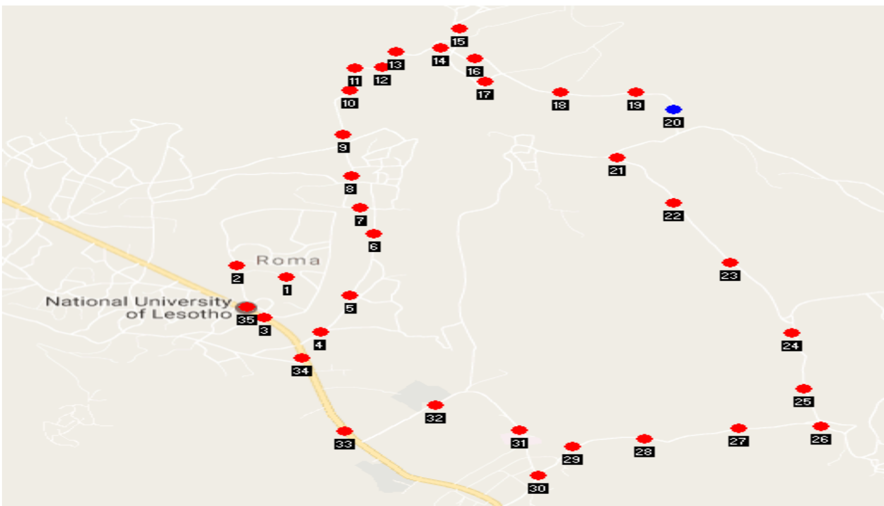


Fig. 13. DTT signal reception test points for villages east of the university campus.

Table 2. The operating parameters used for measurements

Reception Classification	**STB Signal Strength (%)**	**STB Signal Quality (%)**	**STB BER**	**Spectrum Analyzer Signal Strength (dBm)**
Good	> 50%	24% - 30%	~ $1x10^{-9}$	> -50 dBm
Acceptable	37% to 50%	14% - 24%	< $1x10^{-4}$	-50 dBm to -64 dBm
Poor	< 37%	< 14%	> $2x10^{-4}$	< -64 dBm to -69 dBm

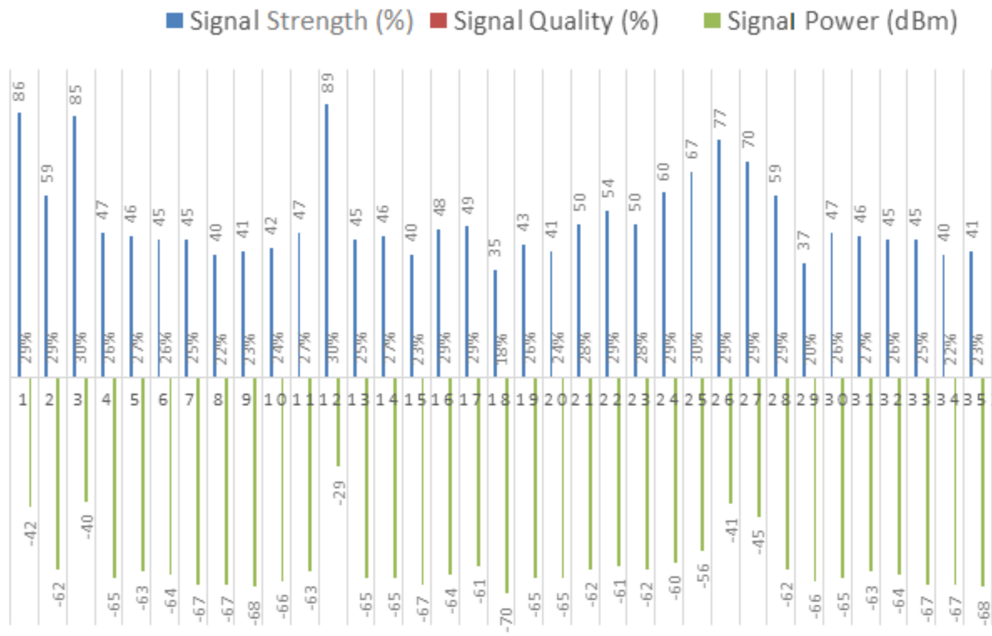


Fig. 14. Measured signal properties for test points in villages east of the university campus

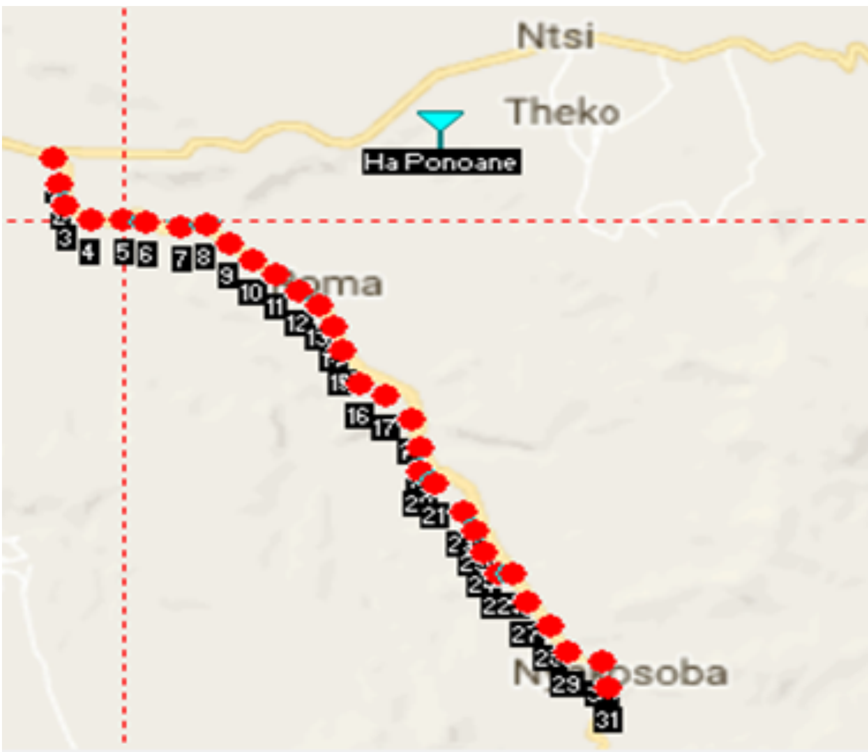


Fig. 15. DTT mobile signal reception test points for the St. Michal's through Roma to Nyakosoba route

C. Mobile Reception Results

Measured signal properties for mobile or portable reception along the A5 route from St. Michaels to Nyokosoba simulated in Figure 15 were taken with the receiving antenna at 1.5 m above ground level. A total of 31 test points spaced at 500 m intervals along the route as illustrated were sampled. For the mobile reception results, the ToV was maintained when the signal strength was 37% or higher and the signal quality was 20% or higher from the STB. The results in Figure 16 indicate that about 6 points (numbered 21, 27 – 31) attained signal strength of less than 37% and signal quality of less than 20%. In fact, for test points 27 to 31, there was no signal recorded at all as the area towards Nyakosoba is in a valley shadowed by mountains. Thus, only about 81% of the test points for mobile route reception received good enough signal level and video quality.

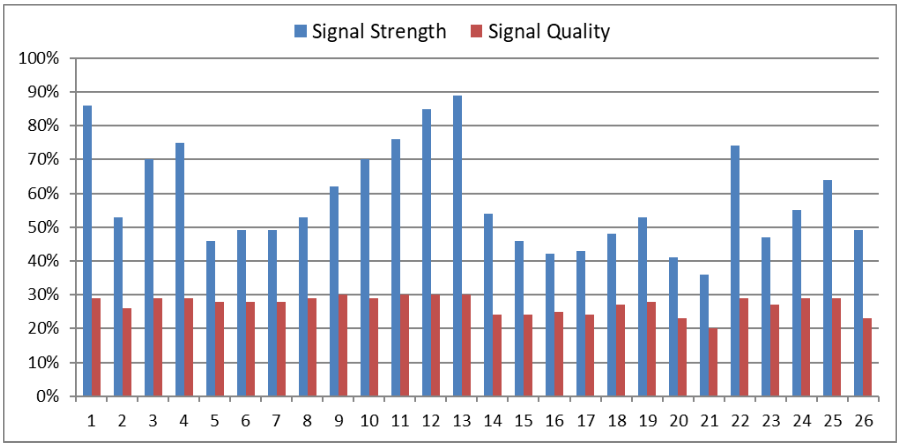


Fig. 16. Measured signal properties for test points in mobile reception along St Michael's to Nyakosoba

5. Conclusion

This study presented the first measurement and verification or validation campaign for Lesotho's digital terrestrial TV network signal reception and decoding, based on DVB-T2 and MPEG-4. The field testing objectives were to measure the actual service versus predicted coverage from computer simulations, and to collect data that will be useful in improving the Lesotho's DTT broadcasting system performance. The study found that at most tests points in the university town of Roma and nearby villages, which are within the coverage area of the main transmitter at Berea Plateau, the transmitter broadcasts the DTT signal with enough level and quality to be decoded without errors and properly viewed on TV screens. Values of the required minimum C/N for quasi-error free reception have been determined to average 23 dB for fixed reception. The study further confirmed the existence of coverage gaps or black spots within the selected measurement test points which are shadowed from the main transmitter by nearby hills and mountains and therefore have poor signal reception as demonstrated by the Radio Mobile simulation results. The reception problem in these shadow areas will be addressed by the gap-fillers once they become operational.

In order to obtain statistically significant results there must be enough data sample points measured to reflect the actual performance of the measured system. Practical considerations lead to a range of 30 to 100 sites, although reasonable statistical confidence intervals may require significantly more tests points, which will be done in future once the whole DTT network is operational.

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Aims and Objectives

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