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EFFECT OF ATMOSPHERIC IMPAIRMENTS ON KU-BAND FREE-TO-AIR DIGITAL SATELLITE TELEVISION SIGNALS IN LAGOS STATE

A. O. Gbenga-Ilori *
DEPT OF ELECTRICAL AND ELECTRONICS ENGINEERING, UNIV. OF LAGOS, AKOKA, LAGOS STATE, NIGERIA
E-mail address: *gbengailori@unilag.edu.ng*

ABSTRACT
With the rapid deployment of free-to-air satellite television, there is an increasing need for an accurate propagation prediction tool for satellite link planning. This paper presents an evaluation of deterministic propagation model that is best for the analysis of satellite signal quality at Ku-band in Lagos state, Nigeria. The paper aims at comparing accurate measurements of channel-to-noise (C/N_0) and bit error rate (BER) taken at six locations within Lagos state with simulation results derived from the Institut für Rundfunktechnik (IRT) model and modified irregular terrain model (ITM) deterministic propagation models. The work considered the effect of the type of modulation scheme and error correction code used on the C/N_0 and BER received using these deterministic propagation models. Results show a deviation of 0.732 dB and 0.285 dB from C/N_o measurements using the IRT and modified ITM models respectively. This work shows that at more than 1% of the time, both models performed well when compared with measurements. However, at less than 1% of the time, which accounts for periods of heavy rainfall, the modified ITM model performed better. The paper also shows that when error correction code is not used with the modulation scheme deployed, the BER increases rapidly and the effect of using a higher alternate modulation symbol is not evident on achievable data rates.

Keywords: *Bit error rate, deterministic propagation models, Ku-band, satellite link planning.*

1. INTRODUCTION

Satellite broadcast transmission in the Ku-band has recently attracted a lot of attention because of the possibility of smaller aperture antennas and lower interference at higher frequencies [1]. However, rain attenuation is a major cause of signal degradation in the Ku-band at frequencies higher than 10 GHz [2]. Lot of work has been done to mitigate rain attenuation due to weather impairment. Many papers reviewed the performance of propagation models for satellite communication. In one of these papers [3], the suitability of ITU-R rain attenuation model for accurately predicting errors in tropical climates was analyzed. In another work [4], authors also considered the performance of the ITU-R propagation model for signal reception analysis in Ku-band for tropical regions. Another work modified the ITU-R model and showed that the modified model was able to achieve significant improvement for analysis of signal attenuation in Ku-band [5].

All of these papers considered ITU-R model, which is a semi-empirical model. Empirical and semi-empirical models are measurement-based models that are site and frequency-specific and therefore difficult to generalize [6]. On the other hand, deterministic models provide a more accurate and site-specific coverage usually requiring terrain information and other site-specific parameters.

Satellite communication in Ku-band is heavily affected by weather factors like rain, clouds, fog, and atmospheric gases. Lagos state, Nigeria is particularly affected by these factors except fog. Due to the location, many cities in the state are in the coastal region and therefore experience heavy rainfall. The state is also the largest industrial state of the country and therefore plagued with atmospheric industrial gases. Due to insufficient national grid power supply, the state which is the most populous in the nation, also suffers from high carbon footprint due to gases

* Corresponding author, tel: +234 803-473-1440

from power generators used as alternative energy sources.

Nigeria is currently implementing its digital switch over (DSO) for television to promote a viable free-to-air (FTA) television platform. FTA television is of importance in a country like Nigeria where the average daily income is very low and the digital divide is widened because of lack of affordability for pay satellite television.

In this paper, the effect of weather conditions on satellite television reception in a tropical and metropolitan area like Lagos with many coastal cities is considered. The paper used the Institut für Rundfunktechnik (IRT) method and modified irregular terrain model (ITM), both of which are deterministic propagation models, to compute the received channel-to-noise (C/N_0) ratio and the bit error rate (*BER*) from six locations in Lagos state. Results derived from the use of these models were compared with measurements taken at these locations in order to validate the efficacy of these deterministic propagation models. The impact of the type of modulation scheme and error correction code used on the performance of the propagation models was also considered in this paper.

The major contributions of this paper are as follows:

- to compute C/N_o and *BER* for FTA digital satellite television signals in the Ku-band using the IRT and modified ITM propagation models, both of which are deterministic models,
- to assess the performance of the two deterministic propagation models used with measured data in order to determine which model is best for Lagos state and areas with similar geographical features,
- to determine which modulation scheme performs best with these deterministic models, and
- to determine the impact of error correction codes on the performance of these deterministic propagation models.

The rest of this paper is organized as follows. Details about the two prediction models used are discussed in section 2 while the measurement set up and procedures are discussed in section 3. The performance of the deterministic models was validated in section 4 by comparing them with measured data. The paper concludes in section 5.

2. PREDICTION MODELING

In this research work, digital satellite television signal strength predictions have been made using two deterministic propagation methods; the modified ITM and the IRT.

2.1. IRT Prediction Method

The IRT prediction method was developed at the Institut für Rundfunktechnik (IRT) for predicting urban and rural propagation loss [7]. The method is essentially based on a slightly modified calculation of the multiple knife-edge diffraction loss [8] after Deygout. The method is a deterministic model and requires actual terrain information for predictions. The procedure of the IRT method can be described as follows.

First, the clutter (building and trees) heights are added to the terrain heights of the propagation path under consideration. This is followed by a description of the profile of the propagation path between the transmitter and receiver in order to determine the obstacles that will contribute to the diffraction attenuation according to the modified Deygout model. Up to seven diffracting obstacles can be accounted for using this method. The obstacles, whether formed by terrain or by buildings, are treated as knife-edge oriented perpendicular to the direction of propagation. The IRT method makes use of a modified Deygout model for determination of diffraction losses [9]. Apart from diffraction losses, the IRT method also determines other losses like reflection, scattering and attenuation.

2.2. Modified ITM Method

One of the widely used large-scale propagation prediction models that take account of irregular terrain effects is the Longley-Rice model [10]. Irregular Terrain Model (ITM) was developed from the Longley-Rice model for computation of terrain-conscious signal attenuation [11]. ITM is a computational model that estimates the signal attenuation over a given path from a set of variables in either a point-to-point or area modes. The area mode provides techniques to estimate the path specific parameters so that gain can be computed when no terrain map is available. ITM's point-to-point was used in this work because of our access to terrain data. Despite the comprehensive nature of Longley-Rice formulae, their manual application to even a simple point-to-point propagation path loss calculation requires a lot of effort. Given this difficulty, the ITM computer program was developed. The program examines the geometry of a radio path along a given terrain profile to determine several important parameters including the distances to the radio horizons from the path endpoints and the total path length. Based on these data, the program determines whether the line-of-sight is obstructed. If there is any obstruction, a combination of knife-edge theory and smooth earth diffraction loss is used. The ITM model also considers ground reflection. However, it does not explicitly address the effect of clutter due to vegetation and buildings. It also considers refraction through a standard atmosphere and also tropospheric scatter. Loss due to reflection is estimated using the two-ray ground reflection model while that due to tropospheric scatter is estimated using scatter theory [12]. The model requires terrain databases to extract terrain information.

The input parameters for the ITM model in the point-to-point prediction model include radio climate, terrain profile, frequency in the range of 20 MHz to 20 GHz, transmitter and receiver height, and surface refractivity.

Some modification has been made to the ITM model in this research work. The ITM model calculates the diffraction loss using [13];

$$A_{diff} = (1-w)A_k + wA_r + A_{fo} \quad , \quad (1)$$

where

w is the weighting factor based on empirical data, [13],

A_{fo} is the clutter factor,

A_k is the double knife-edge loss, and

A_r is the rounded earth loss as defined by Volger's formulation, [14].

The modification done in this work involves the consideration of more than two successive knife-edges in the diffraction loss estimation. This work considers the loss due to more than two knife-edges as a cylindrical surface loss depending on the distance between the knife-edges. When there exist more than two significant and successive knife-edges, the procedure in the modified ITM is to calculate the loss for the path and then add a curvature factor A to it [15]. Equation (1) then becomes;

$$A_{diff} = (1-w)A_k + A + wA_r + A_{fo} \quad , \quad (2)$$

where

$$A = \frac{\left(\lambda^{0.66} r^{0.33}\right)}{h} \quad (3)$$

and λ is the wavelength, in meters, h is the height of the top of the obstruction above the line-of-sight in meters, and r is the effective radius of the curvature of the top of the obstruction, in meters.

2.3. Compensation method for Propagation Model

To compensate for satellite communication atmospheric losses in two the models described in sections 2.1 and 2.2, equation (4) is used to compute the carrier-to-noise ratio C/N ratio.

$$\frac{C}{N_o}\, dB = EIRP + G_r - FSL - L_A - L_s - N_o \; ,(4)$$

where the losses described in the above equation are the free space loss (FSL) and atmospheric losses. EIRP is the Effective Isotropic Radiated Power; and L_A, L_s, and N_o are the atmospheric losses, system losses, and noise spectral density, respectively.

The work also considered the *BER* caused by atmospheric impairments as shown in equation (5):

$$BER \approx \frac{SER}{log_2(M)}, \quad (5)$$

where SER is the symbol error rate, and M is the number of alternative modulation symbols [16]. SER for *M*PSK is calculated as shown in equation (6):

$$SER_{MPSK} = erfc\left[\sqrt{\frac{log_2(M)E_s}{N_o}}\sin\left(\frac{\pi}{M}\right)\right], \quad (6)$$

and energy per symbol to noise (*E_s/N_o*) is expressed as:

$$\frac{E_s}{N_0} = \left(\frac{C}{N}\right)\left(\frac{B}{f_s}\right), \quad (7)$$

where B is the channel bandwidth and f_s is the symbol rate. A MATLAB program was used to implement equations (4) and (5).

3. EXPERIMENTAL SETUP

This section describes the simulation procedure and the measurement set up used to validate our simulation results.

3.1. Simulation Procedure

FRANSY is a frequency analysis software tool used in planning networks for analogue television and digital television, and it is deployed in this work. FRANSY was developed by the Institute for Radio Frequency

Technique (IRT) in conjunction with German broadcasters and the Conterra. The software covers all aspects of coverage analysis, coverage optimization, and network planning. It employs the relevant signal strength prediction models, and considers the data for terrain and clutter. FRANSY is used as a tool for signal strength prediction. It has the IRT model and ITM model incorporated. However, the ITM algorithm was modified in this research work as described in section 2.2.

Geographical data required by FRANSY are divided into three; terrain data, land cover data and GIS data. The digital elevation model (DEM) or terrain data used in this work is from the Shuttle Radar Topographic Mission (SRTM) with a 90m resolution [17]. The Nigerian land cover data used in this work was collected by the US Geological Survey (USGS) using LANDSAT 7 satellite with a resolution of 1km [18]. The GIS data used was collected using the Garmin GPS Map 76 device.

3.2. Measurement

Measurements were taken to test the performance of DVB-S2 in different locations in Lagos for better analysis and validation of the deterministic propagation models used.

The measurements analyzed in this study were carried out in various locations in Lagos state, southwest Nigeria. A six-week measurement campaign was done for this analysis, on periods including rainy and non-rainy days. We used a 65cm offset reflector antenna directed to AzerSpace 2/Intelsat 38 at 41.48^0 elevation angle. The measurement set up used for the field trial, as shown in Figure 1, consists of the reflector antenna, the low noise block (LNB) downconverter, a handheld PROMAX spectrum analyzer, a GARMIN GPS receiver, and a laptop. The spectrum analyzer was used to take the C/N_o and BER measurements while the GPS receiver was used to get data on test location and elevation. The laptop was used for data logging and analysis.

4. RESULTS AND DISCUSSION

In this section, the performance of our propagation models was compared with results from the measurements carried out at different locations in Lagos. The locations used are Lekki, Yaba, Ikorodu, Ikeja, Agege and Surulere. The results were evaluated and analyzed in terms of C/N_o and BER achievable using two different digital modulation schemes. Rain attenuation has a significant effect on satellite communication and it depends on the tropical position of the receiver relative to the equator and also on the surrounding areas. FRANSY and MATLAB were used to conduct the simulation experiments.

The IRT prediction method and the modified ITM were used in FRANSY to predict the EIRP received at the various locations. MATLAB was used to determine the C/N_o and BER for these locations using equations (4) and (5). We also took several C/N_o and BER measurements at these locations in order to validate the performance of our modified ITM model. Simulation parameters used in this paper are shown in Table 1 while measurement parameters are shown in Table 2. The other simulation parameters are functions of the frequency used, terrain irregularities and height of the receiver.

Figures 2 and 3 show the predicted C/N_o for the six locations while Figure 4 shows the measured C/N_o for these locations. Out of the time used to take these measurements, only 2% account for the rainy periods. However, heavy rainfall accounted for less than 0.1% of the time, causing a significant loss of signal quality as shown in Figures 2, 3 and 4. Both deterministic models performed well when compared with measured data. However, as rainfall increases, there was a significant difference in the predicted data from IRT model when compared to measured data.

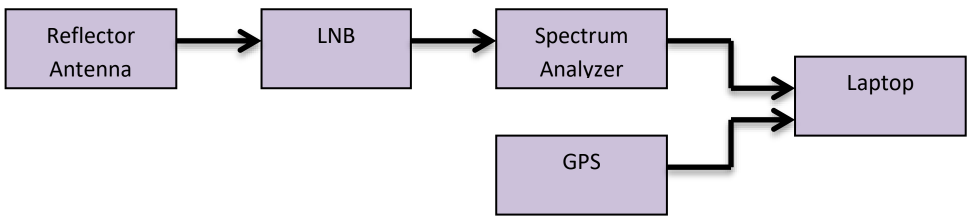

Fig. 1: Measurement Setup

Table 1: Simulation Parameters [19].

Parameter	Value
Modulation Schemes	8PSK, 16PSK
Symbol Rate	30 Msps
Bandwidth	27 MHz
Height of receiver	10m, 20m, 30m
L_A	1 dB, 5 dB and 10 dB
L_S	4 dB
N_0	2 dB
LNA Temperature	270 K
Receiver Antenna G/T	5.9 dBK

Table 2: Measurement parameters

Name	Coordinates Lat./Long.	Antenna Height	Elevation Angle	Antenna Size	Frequency (GHz)
Yaba	6.52551, 3.39091	10m	41.48	65cm	11.59
Surulere	6.48573, 3.35602	32m	41.48	65cm	11.59
Ikorodu	6.62356, 3.50483	18m	41.48	65cm	11.59
Agege	6.65738, 3.30952	14m	41.48	65cm	11.59
Lekki	6.43725, 3.46545	19m	41.48	65cm	11.59
Ikeja	6.57703, 3.36956	12m	41.48	65cm	11.59

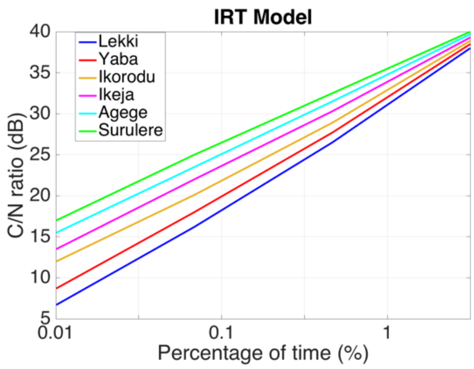

Fig. 2: C/N_o for IRT model

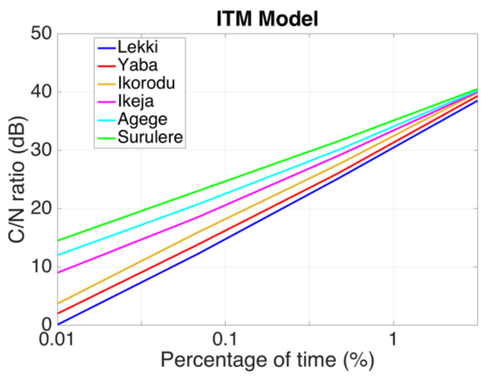

Fig. 3: C/N_o for Modified ITM model

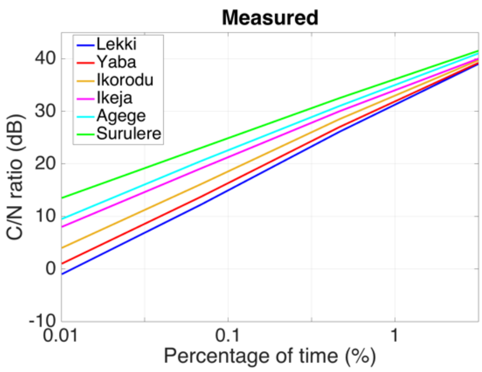

Fig. 4: Measured C/N_o

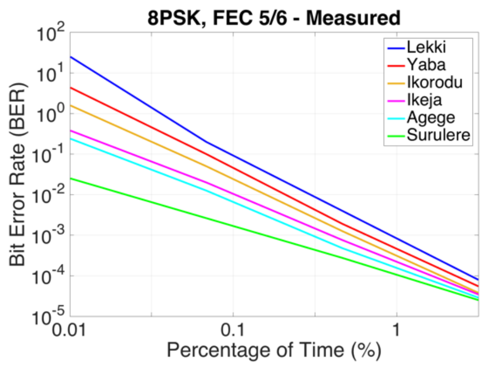

Fig. 5: Measured BER

The C/N_o error between measurements, modified ITM and IRT models are shown in Table 3. Rainfall also had a serious impact on the *BER* predicted using both models. We predicted *BER* using 8PSK modulation scheme with FEC code rate of 5/6. The modulation scheme and code rate were chosen because they are used by the satellite transmitter considered and would be a good basis for comparison with measured data.

Figures 5, 6 and 7 show the BER from measurements, the IRT and modified ITM models respectively. Compared with the measured data, both models predicted the error rate well at over 1% of the time. However, during periods of heavy rainfall, which makes less than 0.1% of the time, modified ITM predicted the errors better than IRT. The BER error between measurements, modified ITM and IRT models are shown in Table 4. The better performance of modified ITM is evident in Table 4 from the lower standard deviation of 0.076 compared with IRT model that has a standard deviation of 0.0113.

Figures 8 and 9 show the observed improvements in *BER* for the two models when the 16PSK modulation scheme is used with a code rate of 5/6 compared to when 8PSK modulation is used. Comparing Figures 6 and 8, the IRT model showed an average *BER* reduction from 6.78×10^{-4} with 8PSK to 9.783×10^{-5} with 16PSK. Comparing Figures 7 and 9, the modified ITM model also showed an average *BER* reduction from 1.498×10^{-4} with 8PSK to 1.36×10^{-5} with 16PSK.

The significance of the error correction used is shown by comparing results of predictions from both models, using 16PSK modulation scheme with FEC code rate of 5/6, with results of prediction using both models with 16PSK modulation scheme and no error correction scheme. Comparing Figures 8 and 10 showed that, using the IRT model, there was an increase in the average *BER* from 9.783×10^{-5} with 16PSK, 5/6 FEC to 3.95×10^{-4} with 16PSK, and no FEC.

Comparing Figures 9 and 11 showed that, using the modified ITM model, there was an increase in the average *BER* from 1.36×10^{-5} with 16PSK, 5/6 FEC to 1.38×10^{-4} with 16PSK, and no FEC. However, the figures indicated that *BER* below 0.05% of the time shows a significant increase from 0.053 to 0.11 with IRT model and 0.0056 to 0.03 with modified ITM model. This reveals that though 16PSK modulation scheme offers better data rates, a good error correction scheme is also needed in order to significantly reduce the losses during heavy rainfall. The effect of the type of modulation and error correction is not very significant in periods with no rainfall. Both IRT and modified ITM models performed comparably well when there is no rainfall.

We compared the results from this work with previous work from the author [20] where both models were used for terrestrial television field strength predictions. For terrestrial television field strength prediction, IRT performed better because it took into consideration terrain factors by treating obstacles as multiple knife-edges. The terrain factors heavily compensated for in the IRT model are the major causes of losses in terrestrial propagation. However, we can see that modified ITM performed better with satellite television predictions because terrain is not the major sources of losses due to the height of the satellite transmitter. The modified ITM model was able to effectively consider ground reflection and refraction due to standard atmospheric and tropospheric scatter.

Table 3: Error between Measurements and Propagation Model Results

DVB-S Measurement Location	*C/N_0* Error Measurement and IRT (Average)	Measurement and Modified ITM (Average)
Lekki	3.325	0.650
Yaba	3.625	0.550
Ikorodu	3.300	0.425
Ikeja	2.350	0.650
Agege	2.700	1.250
Surulere	1.675	0.750
Mean	2.830	0.713
Standard Deviation	0.732	0.285

Table 4: Error Between BER Measurements and Propagation Model Results

DVB-S Measurement Location	*BER* Error	
	Measurement and 8PSK, FEC 5/6 IRT (Average)	Measurement and 8PSK, FEC 5/6Modified ITM (Average)
Lekki	0.0304	0.0203
Yaba	0.0123	0.0105
Ikorodu	0.0077	0.0058
Ikeja	0.0031	0.0022
Agege	0.0013	0.0011
Surulere	0.0008	0.0008
Mean	0.0093	0.0068
Standard Deviation	0.0113	0.0076

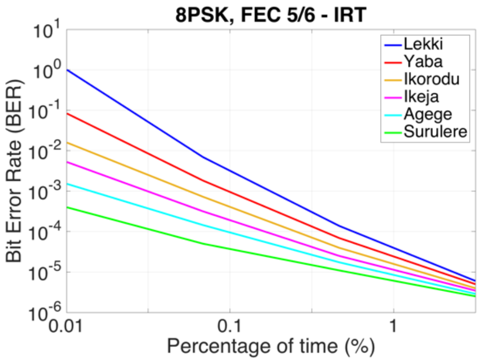

Fig. 6: BER 8PSK, 5/6 IRT model

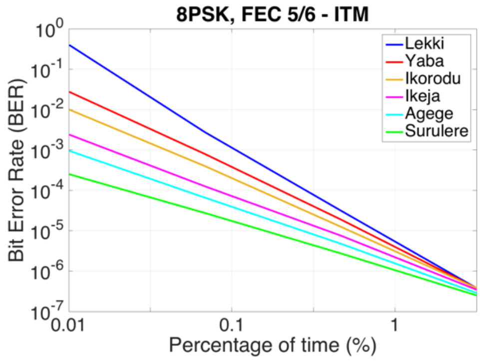

Fig. 7: BER: 8PSK, 5/6 Modified ITM

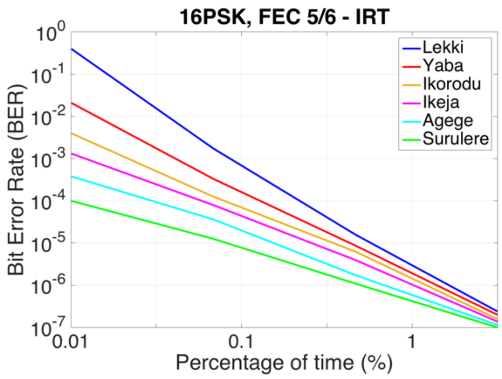

Fig. 8: BER 16PSK, 5/6 IRT model

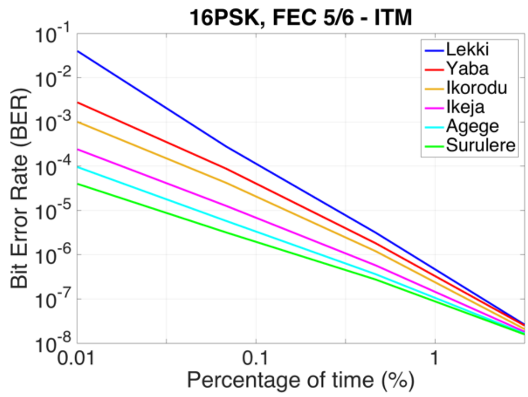

Fig. 9: BER 16PSK, 5/6 modified ITM

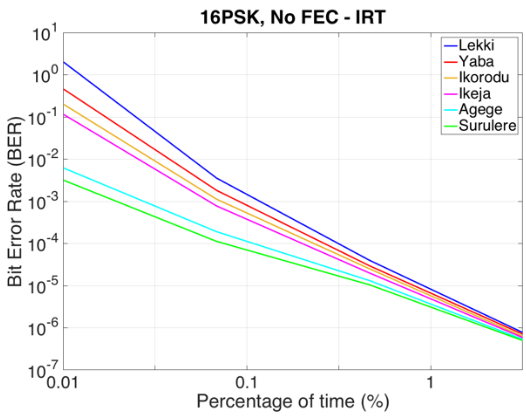

Fig. 10: BER 16PSK, NO FEC IRT model

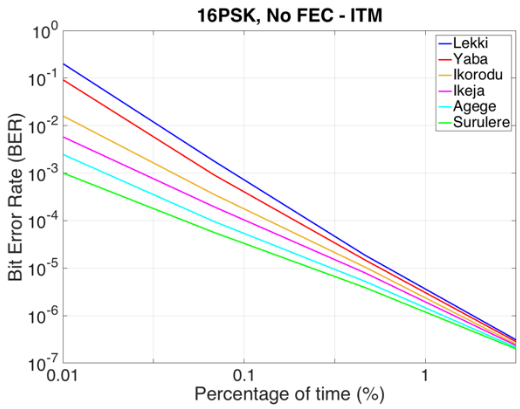

Fig. 11: BER 16PSK, NO FEC modified ITM

5. CONCLUSION

In this paper, measured C/N_o and *BER* recordings in six locations within Lagos state, Nigeria has been compared with results from the IRT and modified ITM prediction models. Both models, being deterministic, provide more accurate results compared to empirical models as they incorporate weather, terrain and clutter information in the determination of the parameters of interest. Results show a deviation of 0.732 dB and 0.285 dB from C/N_o measurements using the IRT and modified ITM models respectively. This work shows that at more than 1% of the time, both models performed well when compared with measurements. However, at less than 1% of the time, which accounts for periods of heavy rainfall, the modified ITM model performed better because it puts accounts for refraction loss due to standard atmosphere and tropospheric scatter. The paper also shows that the 16PSK offer higher data rates with FEC. However, without FEC, the *BER* increases and the performance of 8PSK with FEC is comparable to 16PSK without FEC showing that the effect of the higher alternate modulation symbol used is not evident on achievable data rates. This indicates that error correction is important during conditions with weather impairments.

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