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Evaluation of Rain Degraded Digital Satellite Television Reception in Tropical Regions

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Abstract— The loss of digital satellite television content to the prevailing impact of rain is still a major concern to satellite operators, television content providers and subscribers as well. In this paper, impairment resulting from rain, in the form of signal attenuation is quantified on 148 satellite-earth links over 37 different locations using four geostationary satellites with footprints extending well over the tropical landmass of Nigeria. Initial result from experimental campaign effort in Akure, South-West, Nigeria is compared with predictions using the ITU-R global model. The distribution of the rain attenuation quantified on NIGCOMSAT 1-R, EUTELSAT 36B, INTELSAT 20 and NSS7 downlinks reveals the spatial variability of rainfall effect on the links from the South-South to the North-Eastern part of Nigeria. The link performance is evaluated using the energy per bit to spectral noise ratio (E_b/N_0) and result indicates that 99.99 – 99% availability is possible over the selected links across Nigeria, while links characterized with lower elevation angles are found to be much more susceptible to the loss of the digital television signal. Results from the measurement campaign reveal an abrupt squelching of received signal, resulting into complete loss of the digital television content around 64 mm/h, while the point rain rate ($R_{0.01}$) estimated over the observation period is 100 mm/h. Observation from comparison however indicates that the typical user experience on the impairing effects of rain on digital satellite television reception is completely different from predictions.

Index Terms— Digital satellite television reception, rain rate, rain attenuation, link performance.

1 Introduction

Like any other communication application or service operating above 10GHz, the digital satellite television also experiences signal extinction during high-intensity rainfall events. The degradation affects the quality of the television content delivered to subscribers, often presenting frozen frames and blocking as prominent artifacts, while the rain-faded digital satellite signal is completely lost whenever the received signal level drops below the noise floor [1].

This effect of rain on signal propagation has drawn a considerable attention globally. The degrading effect at frequencies above 10 GHz [2, 3] and the prevailing influence in the tropical and subtropical regions is evidenced in recent contributions, especially from locations where rainfall is characterised with high and rapidly varying intensities. Although several regional and national campaigns have produced suitable rain attenuation models over the years, most of these models are not universally optimal in performance.

Consequent upon this inadequacy, a number of experimental efforts have been conducted to quantify rain attenuation in the Ku band and higher frequency bands, particularly on the satellite downlink. For example, Choi [4] established agreement between measured and predicted rain attenuation for Korea at 12.25 GHz. In his study, the performance of selected global rain attenuation models was investigated and the ITU-R model was found suitable for Korea. A similar effort by Boonchuk et al. [5] reports a contrary performance for the ITU-R and Crane global models over Bangkok. For beacon measurement at 12.7 GHz, they observed that the selected models underestimate rain attenuation for equatorial Bangkok. Another experimental propagation measurement by Suryana et al. in Indonesia also estimated ain attenuation on satellite downlink using two-year measurement at 12.247 GHz. Results from their comparative analysis indicate that the ITU-R model overestimates rain attenuation for Indonesia [6].

The situation is quite different in tropical Nigeria, where little has been reported on the suitability of existing rain attenuation models for optimal communication design purposes. Notable however are the contributions providing rain attenuation estimates for satellite links via prediction. Recently, Ojo et al. in [7] developed contour maps for rain attenuation distribution over Nigeria using the ITU-R model at 12.675 and 19.45 GHz on NIGCOMSAT downlink. More recent estimates by Omotosho and Oluwafemi [8] presents cumulative distribution of rain attenuation across the 6 geopolitical zones in Nigeria. The NIGCOMSAT-1 link was also considered since it is the indigenous communication payload for Nigeria. More recently, Adeyemo et al. in [9] investigated the applicability of the Garcia and ITU-R rain attenuation models on the NIGCOMSAT-1R link at 30 GHz over Nigeria.

Due to the increasing penetration of the digital satellite television and its importance in the on-going transition from analog to digital terrestrial television broadcast, this study aims to experimentally quantify the effect of rain on satellite-earth link, using a prominent digital satellite television reception setup at the Ku band – digital television content from Multichoice on leased EUTELSAT 36B Ku band transponder. The performance of digital TV delivered by other notable satellites with footprints extending well over Nigeria is also investigated. The rain induced attenuation on 148 satellite-earth links is determined using the knowledge of point rainfall rate distribution over Nigeria, while the performance of the links is quantitatively verified.

2 Experimental campaign in Nigeria

Due to the rising demand for high definition television (HDTV) broadcast content by residential users and terrestrial broadcast stations for onward distribution within defined coverage areas, it is important to quantify impairments by rain on the satellite-earth link, particularly using experimental measurement.

The experimental measurement campaign is setup at the Federal University of Technology, Akure (7.17⁰ N, 5.18⁰ E), South-West, Nigeria. It comprises equipment configured and calibrated to concurrently measure precipitates and digital satellite television signal. The precipitate measurement setup is made up of the Davis Vantage Vue electronic weather station, which logs rain rate and other meteorological parameters at the required 1-minute integration time.

The Integrated Sensor Suit (ISS) of the weather station is co-located with the 90 cm offset parabolic antenna - horizontally polarized and at a look angle of 53.2^0. The down-converted Ku-band signal from EUTELSAT 36B (geo-stationed at 36^0 East) is fed to a digital satellite meter (SATLINK WS-6936) and a spectrum analyzer (GWINSTEK GSP-827) for signal level monitoring and logging into a storage unit, as presented in Figure 1(a). The outdoor unit is shown in Figure 1(b).

The 1-minute rain rate and the corresponding signal level statistics is recorded for reception on 12.245 GHz at the earth station end of the 36880.12 km link during clear air and during the peak raining period between July and December, 2012. The satellite has an expansive footprint over Nigeria and Sub-Saharan Africa and it delivers 48 dBW of effective isotropic radiated power (EIRP) over the measurement site and in most other parts of the country.

3 Digital Satellite Television Reception over Nigeria

Nigeria is a large and populous nation covering an area of 923,768 square meters. It is encompassed by a geographical window with lower left geographic coordinate of (2.72^0 E, 4.297^0 N), (14.19^0 E, 4.29^0 N) at the lower right, (2.72^0 E, 13.88^0 N) at the upper left and at the upper right we have (14.91^0 E, 13.88^0 N) [10]. Detailed distribution of the point rain rate - $R_{0.01}$ (mm/h) used is available in [11] as estimates over Nigeria. The earth station ends of the links are described as television receive only (TVRO), as indicated in Figure 2, which shows the selected sites over the existing rain rate distribution over Nigeria.

The chosen sites are deliberately selected for equal representation of the differing physical and climatic details over Nigeria. The elevation angle is an important parameter for the prediction of rain attenuation and it is dependent on both the orbital position of the selected satellites and the geographical description (longitude and longitude) of the earth station [12]. Hence, the look angle varies significantly over the design links and from one site to another.

3.1 System Characteristics

The design setup is based on the downlink assessment of digital television services by four direct broadcast satellites (DBS), each delivering digital satellite television contents with footprints extending well over Nigeria. The characteristic of these space vehicles is presented in Table 1. Apart from the recently launched NIGCOMSAT-1R, all other three satellites are active and they deliver DTH services in either pay or free-to-air

TABLE 1

CHARACTERISTICS OF THE DIRECT BROADCAST SATELLITES

Communication Satellite	Orbital position	EIRP (dBW)	Transmit Frequency (GHz)
NIGCOMSAT 1-R	42.5^0 E	50 - 52	12.000
EUTELSAT 36B	36^0 E	48	12.245
INTELSAT 20	68.5^0 E	48.5	12.722
NSS 7	22^0 W	47.2 - 49.3	12.736

Fig.1(a). Indoor unit of the experimental measurement campaign

Fig. 1(b). The outdoor unit

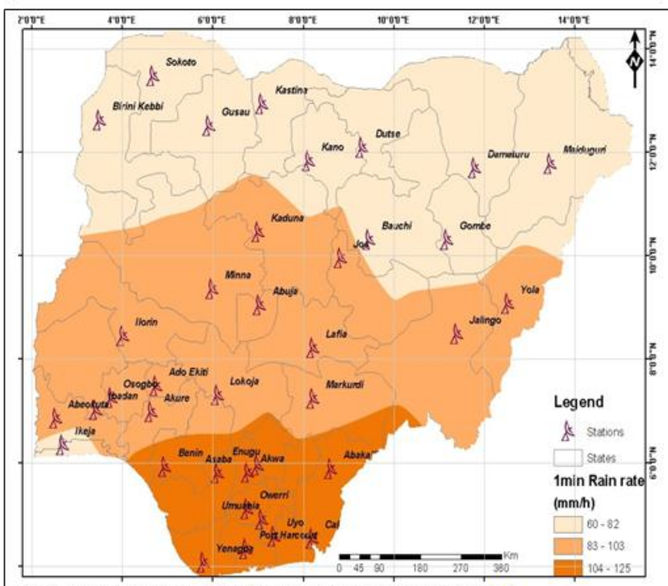

Fig. 2. Point rainfall rate ($R_{0.01}$) distribution and TVRO systems over Nigeria [11]

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schemes over Nigeria.

The receiver front-end is made up of low noise block-down converter (LNB) and offset parabolic dish. The effective isotropic radiated power (EIRP) received at each of the sites is extrapolated from respective satellite footprint and the corresponding receiver antenna sizes [13], varying between 0.65 m to 0.85m is considered for the predictions. The receiver antennas are vertically polarised and then down-converted using a LNB with a noise figure of 0.3 dB over the 148 links over Nigeria.

3.2 Rain attenuation estimates

The attenuation induced by rain on the TVRO systems is estimated for arbitrary percentages of the time in a year. The 37 TVRO earth stations are seeing the satellites at different look angles, thus possessing distinct paths to each of the selected satellites. The respective link distances and the effective path lengths were calculated as shown in Table 2.

The estimation is based on the series of procedures available in [14], which is the ITU-R recommendation in force. Rain attenuation is an integral of the specific attenuation along the propagation path. The rain attenuation exceeded at 0.01% of the time is given as $A_{0.01}$ (dB) and defined by the expression [14]:

$$A_{0.01} = \gamma_R L_E \quad [\text{dB}] \tag{1}$$

where γ_R is the specific attenuation (dB/km) and L_E (km) is the effective path length, which is a function of a horizontal reduction factor and the vertical adjustment factor as detailed in [14]. Details of the frequency (GHz), elevation angle (degrees), point rainfall rate for 0.01% of an average year (mm/h), latitude (degrees) and the earth station altitude (km) are required for this prediction. Estimates for other percentages of the time are calculated using the procedures detailed in [14].

Although rain cell shape and size are also employed for rain attenuation modelling, the computation here is based on the prediction of specific attenuation at 12, 12.245, 12.722 and 12.736 GHz using the point rain rate $R_{0.01}$ (mm/h) distribution available in [11] over Nigeria.

The expression for specific attenuation is given as [15]:

$$\gamma_R = k\left(R_{0.01}\right)^{\alpha} \ [\text{dB/km}] \tag{2}$$

where k and α are frequency and polarization dependent factors estimated from the following:

$$k = \left[k_H + k_V + (k_H - k_V)\cos^2\theta\cos 2\tau\right]/2 \tag{3}$$

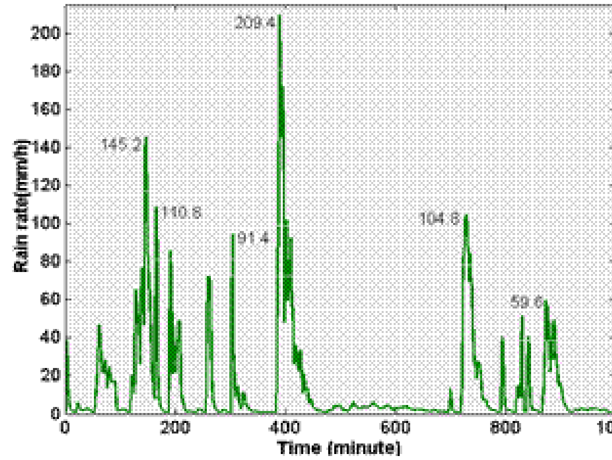

Fig. 3(a) Time series for rain events in October, 2012

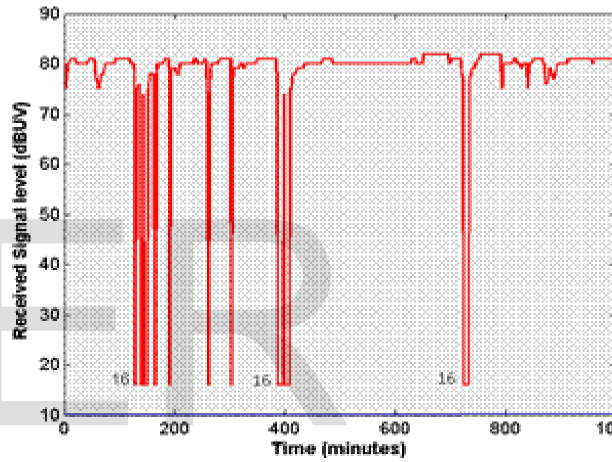

Fig. 3(b) Rain-induced signal outages in October, 2012

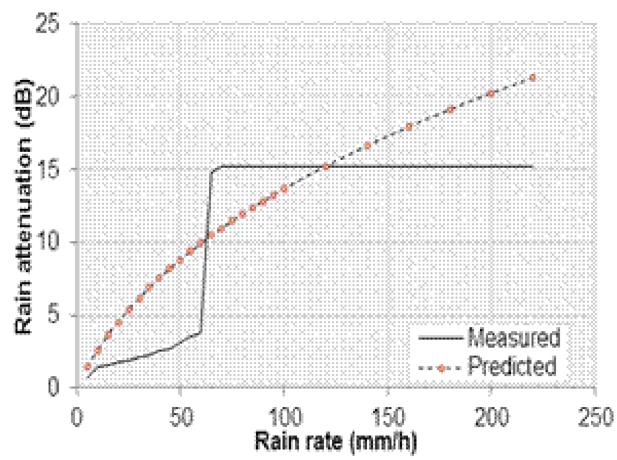

Fig. 3(c) Rain-induced attenuation on the digital satellite television link

$$\alpha = \left[k_H\alpha_H + k_V\alpha_V + (k_H\alpha_H - k_V\alpha_V)\cos^2\theta\cos 2\tau\right]/2k \tag{4}$$

where k_H, k_V, a_H and a_V are the vertical and horizontal components of k and a respectively, θ is the elevation angle and τ is the polarization tilt angle.

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TABLE 2.
THE PHYSICAL AND EFFECTIVE PATH LENGTHS FOR THE SATELLITE- EARTH LINKS OVER NIGERIA.

STATE CAPITAL	Lat. (˚N)	Long. (˚E)	Height above sea level (km)	NIGCOMSAT 1R (42.5^0 E)		EUTELSAT 36B (36^0 E)		INTELSAT 20 (68.5^0 E)		NSS7 (22^0 W)	
				D *(km)*	L_E *(km)*	*d* *(km)*	L_E *(km)*	*d* *(km)*	L_E *(km)*	*d* *(km)*	L_E *(km)*
ABEOKUTA	7.07	3.21	0.074	37.48	3.36	37.00	3.12	39.88	6.91	36.23	3.19
ADO-EKITI	7.63	5.22	0.363	37.33	3.04	36.88	2.89	39.68	5.97	36.16	3.03
AKURE	7.18	5.12	0.303	37.33	3.03	36.88	2.88	39.68	5.96	36.16	3.02
IBADAN	7.21	4.01	0.134	37.42	3.17	36.95	2.97	39.80	6.40	36.20	3.08
IKEJA	6.59	3.34	0.038	37.47	3.55	36.99	3.30	39.87	7.28	36.22	3.38
OSOGBO	7.42	4.31	0.229	37.40	3.10	36.93	2.91	39.77	6.21	36.19	3.02
ABAKALIKI	6.18	8.7	0.149	37.06	2.54	36.64	2.56	39.31	4.63	36.02	2.80
AKWA	6.12	7.04	0.159	37.18	2.74	36.74	2.70	39.48	5.13	36.07	2.92
ENUGU	6.24	7.24	0.139	37.17	2.75	36.73	2.70	39.46	5.17	36.07	2.92
OWERRI	5.48	7.03	0.158	37.17	2.59	36.74	2.54	39.47	4.91	36.06	2.74
UMUAHIA	5.3	7.33	0.165	37.15	2.58	36.72	2.54	39.44	4.86	36.05	2.75
ASABA	6.1	6.44	0.152	37.22	2.76	36.78	2.67	39.54	5.29	36.09	2.87
BENIN	6.22	5.39	0.042	37.30	2.94	36.85	2.80	39.65	5.77	36.13	2.96
CALABAR	4.96	8.33	0.37	37.08	2.76	36.65	2.74	39.34	5.04	36.02	3.00
PORT- HARCOURT	4.77	7.01	0.018	37.17	2.75	36.73	2.70	39.47	5.21	36.06	2.92
UYO	5	7.57	0.163	37.13	2.58	36.70	2.56	39.42	4.84	36.04	2.78
YENAGOA	4.55	6.16	0.093	37.23	2.65	36.78	2.57	39.56	5.15	36.08	2.76
ABUJA	9.04	7.28	0.334	37.20	2.92	36.77	2.84	39.47	5.43	36.11	3.05
ILORIN	8.5	4.55	0.304	37.40	3.16	36.93	2.97	39.75	6.31	36.20	3.08
LAFIA	8.29	8.34	0.403	37.11	2.96	36.69	2.92	39.36	5.35	36.06	3.18
LOKOJA	7.47	6.44	0.204	37.24	3.03	36.80	2.92	39.55	5.75	36.11	3.11
MARKURDI	7.41	8.35	0.142	37.10	2.97	36.68	2.95	39.35	5.39	36.05	3.21
MINNA	9.33	6.33	0.152	37.28	3.22	36.83	3.09	39.57	6.10	36.15	3.27
JOS	9.58	8.57	0.111	37.12	3.00	36.70	2.98	39.35	5.41	36.08	3.22
BIRNIN-KEBBI	12.28	4.08	0.244	37.50	3.67	37.04	3.43	39.84	7.29	36.30	3.51
GUSAU	12.18	6.27	0.044	37.33	3.59	36.90	3.42	39.61	6.75	36.22	3.59
KADUNA	10.32	7.25	0.605	37.23	2.96	36.80	2.86	39.49	5.47	36.14	3.06
KANO	11.56	8.26	0.566	37.18	3.26	36.76	3.17	39.40	5.84	36.14	3.42
KASTINA	12.56	7.33	0.059	37.27	3.64	36.84	3.50	39.51	6.65	36.19	3.72
SOKOTO	13.05	5.15	0.247	37.44	3.82	36.99	3.59	39.74	7.34	36.28	3.72
BAUCHI	10.18	9.46	0.665	37.07	3.02	36.66	2.98	39.26	5.28	36.07	3.29
DAMATURU	11.44	11.58	0.451	36.95	3.32	36.58	3.32	39.07	5.47	36.05	3.74
DUTSE	11.8	9.3	0.452	37.11	3.28	36.71	3.23	39.30	5.74	36.11	3.52
GOMBE	10.19	11.02	0.422	36.97	3.24	36.58	3.25	39.11	5.43	36.03	3.63
JALINGO	8.54	11.22	0.304	36.92	2.82	36.54	2.88	39.07	4.75	35.99	3.22
MAIDUGURI	11.51	13.09	0.343	36.86	3.30	36.50	3.29	38.92	5.24	36.02	3.80
YOLA	9.07	12.24	0.207	36.87	3.08	36.49	3.12	38.98	5.02	35.98	3.55

where d is the physical path length (km) and L_E is the effective path length (km)

Since the quick reference values for these parameters are not available for 12.722, 12.245 and 12.736GHz, the values for k_H, k_V, a_H and a_V are calculated using the following [15]:

$$\log_{10} k = \sum_{j=i}^{4} a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j}\right)^2\right] + m_k \log f + c_k \quad (5)$$

$$\alpha = \sum_{j=1}^{5} a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j}\right)^2\right] + m_\alpha \log_{10} f + c_\alpha \quad (6)$$

where a_j, b_j, c_j, m_k, m_α, c_k and c_α are constants defined for estimating the corresponding values of k_H, k_V, a_H and a_V.

3.3 Performance Assessment

The quality of interest in the assessment of the performance of the TVRO systems is the ratio of energy per bit to spectral noise density (E_b/N_0). As a function of the bit error rate (BER), it is considered as the fundamental prediction tool for evaluating the performance of a digital communication link, particularly at the physical layer. The required error statistics dictates the value of E_b/N_0 that must be available at the receiver input in order to meet the defined performance threshold [16].
The carrier to noise (*C/N*) for reception at the TVRO system is given as follows [16-18]:

$$C / N = RSL - P_N \quad [\text{dB}] \quad (7)$$

where RSL is the received signal level and P_N is the noise power.

$$RSL = P_T + G_T - L_{FS} + G_R - A_R - A_G - A_W - L_O \quad [\text{dB}] (8)$$

where P_T is the transmit power (dB), G_T is the gain of the transmitter antenna (dB), G_R is the receive antenna gain (dB),

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L_{FS} is free space loss (dB), A_R is the rain induced attenuation, A_G is the attenuation due to gaseous absorption, A_W is wet antenna loss and L_O represents other losses (cable loss and other losses in the receiver). The wet antenna loss is not considered in the prediction. The noise power is given as:

$$P_N = kT_{SYS}B \quad \text{[dB]} \tag{9}$$

where k is the Boltzmann's constant, T_{SYS} is the system temperature and B is the transponder bandwidth (MHz).
The noise generated in the receiver is another source of performance degradation on the link [19]. It is also a function of the attenuation induced by rain, gaseous absorption and other various noise sources.
The system temperature T_{SYS} is defined as [18, 20]:

$$T_{SYS} = T_{SKY} + T_{RCV} + T_{OTHER} \quad \text{[K]} \tag{10}$$

$$T_{SKY} = T_{RAIN} \quad \text{[K]} \quad \text{for } R_r > 0 \text{ mm/h} \tag{11}$$

$$T_{SKY} = T_{CLEAR} \quad \text{[K]} \quad \text{for } R_r = 0 \text{ mm/h} \tag{12}$$

where T_{SKY} is the sky temperature, T_{CLEAR} is the temperature in clear air and T_{RAIN} is the temperature due to attenuation in-

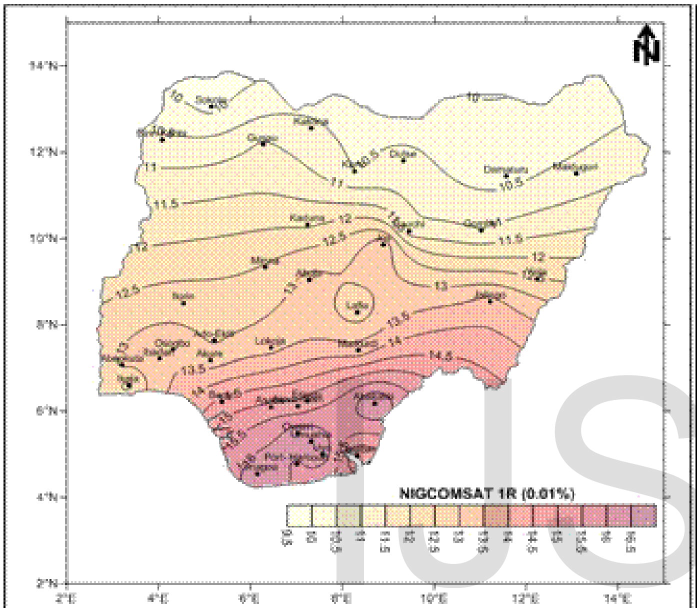

Fig. 4(a). Rain induced attenuation (dB) for digital satellite television reception on NIGCOMSAT-1R links over Nigeria at 0.01% of time

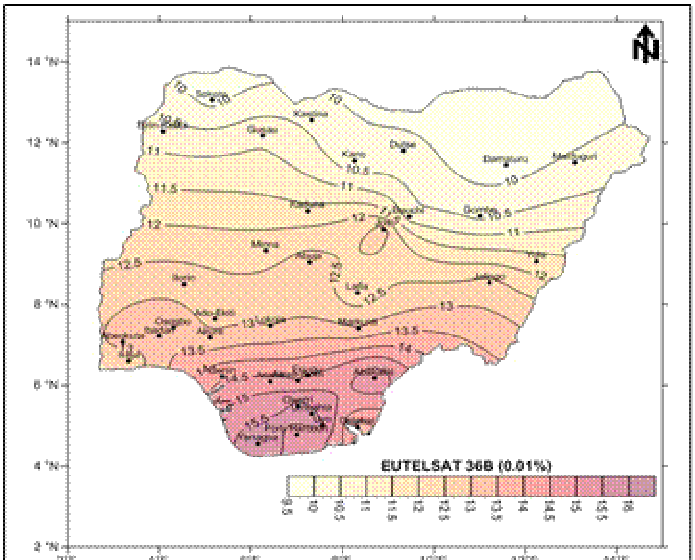

Fig. 4(b). Rain induced attenuation (dB) for digital satellite television reception on EUTELSAT 36B links over Nigeria at 0.01% of time

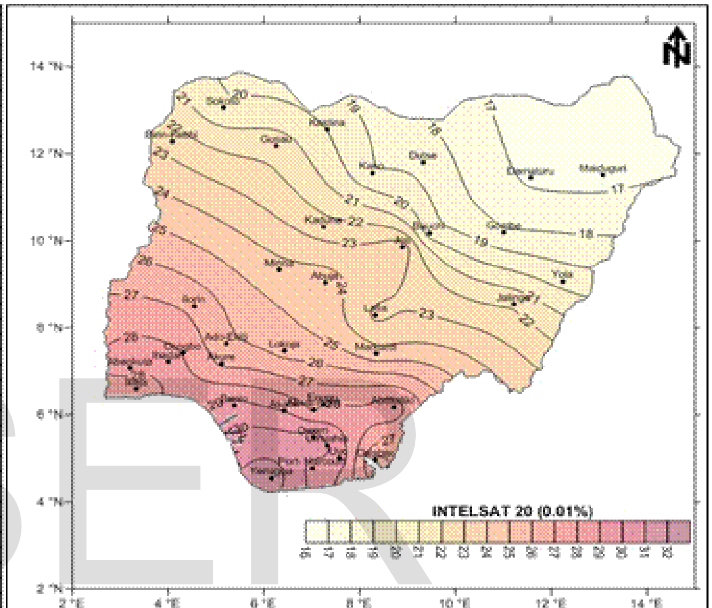

Fig. 4(c). Rain induced attenuation (dB) for digital satellite television reception on INTELSAT 20 links over Nigeria at 0.01% of time

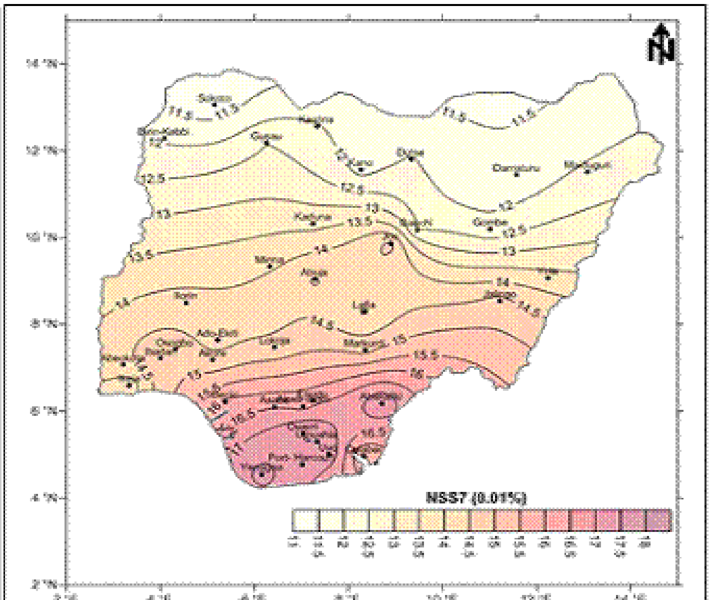

Fig. 4(d). Rain induced attenuation (dB) for digital satellite television reception on NSS7 links over Nigeria at 0.01% of time

TABLE 3
SIMULATION PARAMETERS

Receiver Characteristics		Characteristics of noise sources		Television content characteristics	
Antenna aperture	70%	T_{GL}	3 K, R_r = 0mm/h 18 K, R_r = 0mm/h [18]	*Digital television standard*	DVB-S
Receive antenna sizes	0.6 – 0.85 (m)	T_{ATM}	290^0K as average over Nigeria [23]	*Modulation*	QPSK
Polarization	Vertical	T_{Other}	30 K	*Transponder bandwidth*	36 MHz
Polarization tilt angle	90^0	T_{SKY}	Varies over the links	*Bit rate*	2 MHz
Noise Figure	0.3 dB	T_{LNB}	20.74 dBK	*BER*	10^{-8}

duced by rain, T_{RCV} the receiver temperature, T_{OTHER} is the contribution from other noise sources, particularly those from the surrounding environment of the receiver [18, 20] and R_r is rain rate (mm/h).
The noise temperature for clear sky T_{CLEAR} and rainy session T_{RAIN} is expressed as follows [18, 20]:

$$T_{CLEAR} = \frac{T_{GL}}{A_G} + T_{ATM}\left(1 - \frac{1}{A_G}\right) \quad [\text{K}] \qquad (13)$$

$$T_{RAIN} = \frac{T_{GL}}{A_G A_R} + T_{ATM}\left(1 - \frac{1}{A_G A_R}\right) \quad [\text{K}] \qquad (14)$$

A_R is the estimated rain attenuation (dB) and A_G is the attenuation due to gaseous absorption given as 0.14 dB, as average over Nigeria [21]. T_{GL} is the galactic/cosmic noise [22], while T_{ATM} is the atmospheric temperature which is obtained for each of the sites using ITU-R P.835-5 [23].
The received energy per bit to noise spectral density is therefore expressed as [12, 18]:

$$E_b / N_O = C / N - 10\log R + 10\log B \quad [\text{dB}] \qquad (15)$$

where R is the data rate in bit/s and B is the transponder bandwidth in MHz.

The predicted E_b/N_0 $_{(RECEIVED)}$ is compared with E_b/N_0 $_{(REQUIRED)}$, the latter being the reference energy per bit to spectral noise density for the modulation standard employed. The quadrature phase shift keying (QPSK) modulation was considered since it has been in active use due to its bandwidth saving capacity and the capability of managing system complexity [24]. As often employed for modulation on the digital video broadcasting – satellite (DVB-S) standard [25], a reference E_b/N_0 threshold of 12 dB is therefore considered for 10^{-8} BER [12, 26]. Detailed in Table 3 are the parameters considered for the prediction.

The received E_b/N_o predicted is mainly based on the free space loss and rain attenuation on the links, attenuation due to gaseous absorption and the noise from other sources. Wet antenna loss is not considered for this prediction, while 3 dB is assumed for other losses.

4 INITIAL RESULTS FROM THE EXPERIMENTAL MEASUREMENT IN NIGERIA

The point rainfall intensity for Akure was estimated from the 1-minute precipitate statistics. Result indicates that the required $R_{0.01}$ is 100 mm/h. This is quite close to the 102 mm/h, which was earlier estimated in [27] using the 1-minute rain rate data obtained from a vertically looking micro rain radar (MRR) and the 110 mm/h estimated in [28] over the same measurement site. Comparison with the predicted rain rate in [27] however reveals the underestimation of the required $R_{0.01}$ by the global ITU-R [29] model for this same location.
The maximum rainfall rate for the measurement period was recorded in October with a value of 209.4 mm/h. From the total number of 17 rain events, which is the cumulative rainfall occurrence in October, the highest signal outage of 68 minutes was recorded over the observation period. Figure 3(a) presents the time series for the rain events recorded in the month of October, 2012. The observed degradation on the received signal is as shown in Figure 3(b).

Experimental estimates for the rain induced attenuation on the satellite link is shown in Figure 3(c) for the entire observation period. An abrupt drop in the signal level was observed around 64 mm/h of the rainfall intensity and remains flat at higher rainfall intensities – indicating a complete loss of the digital television content. Although the sudden attenuation could be linked to the high rainfall intensity resulting from the convective rain type in this tropical measurement site, other physical and microstructural features of the precipitate data, and the characteristics of the digital satellite receiver equipment is currently being probed. This would be examined over a longer period as measurement is still ongoing in Akure, Nigeria.

5 SPATIAL VARIABILITY OF RAIN ATTENUATION ESTIMATES

Rain induced attenuation on 37 TVRO systems was estimated at 99 - 99.999% availability across 148 satellite-earth links over Nigeria. The simulation is based on a vertically polarised receiver antenna configuration, since horizontally polarized antennas are much more susceptible to rain induced attenuation [19]. For $R_{0.01}$ varying between 60 mm/h at Sokoto (North-West) and 125 mm/h at Abakaliki, Owerri and Umuahia (South-East) [11], the equivalent rain attenuation was predicted on the links using ITU-R P.618-10 recommendation.

Results show that the quantified rain attenuation varies significantly from the South-Southern parts of Nigeria to the North-Eastern parts. Figure 4(a) - (d) shows the rain attenuation distribution at 0.01% of the time over Nigeria. As rain attenuation increases with corresponding decrease in probability of occurrence over the entire link, the highest attenuation was observed at 0.001% of the time and the value is 52.06dB. The lowest was observed at 1% of the time with a value of 0.77dB. Rain attenuation distribution over Nigeria at 0.001% is shown in Figure 4(e) - (h).

Results from the rain attenuation statistics indicate that Yenagoa (South-South) is the most vulnerable site to signal disruptions and outage. The highest rain attenuation value was observed at Yenagoa across links on the selected satellites. The least attenuation values were recorded at Damaturu, Maiduguri (North-East) and Sokoto (North-West) Nigeria. Links with relatively lower elevation angles recorded correspondingly higher rain attenuation values, a typical observation on

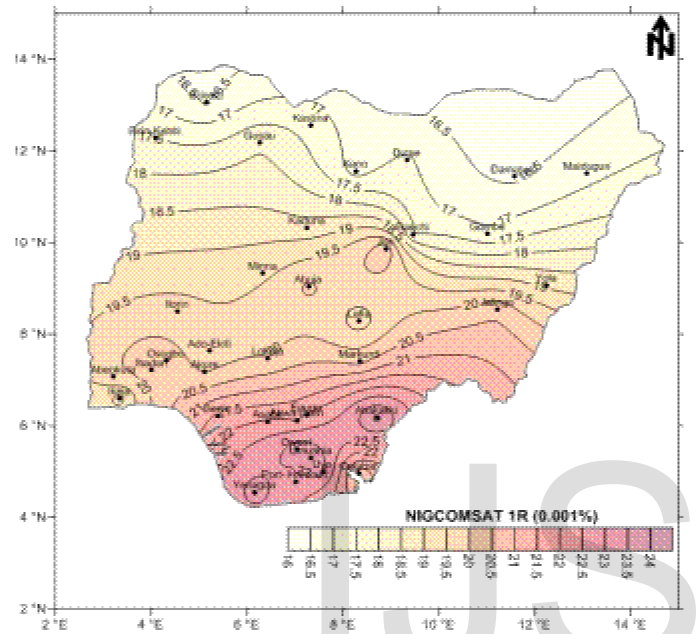

Fig. 4(e). Rain induced attenuation (dB) for digital satellite television reception on NIGCOMSAT-1R links over Nigeria at 0.001% of time

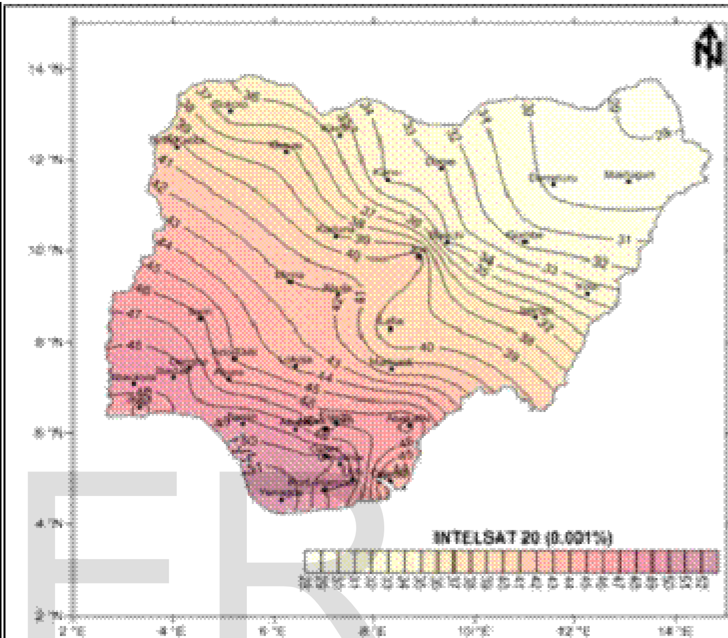

Fig. 4(g). Rain induced attenuation (dB) for digital satellite television reception on INTELSAT 20 links over Nigeria at 0.001% of time

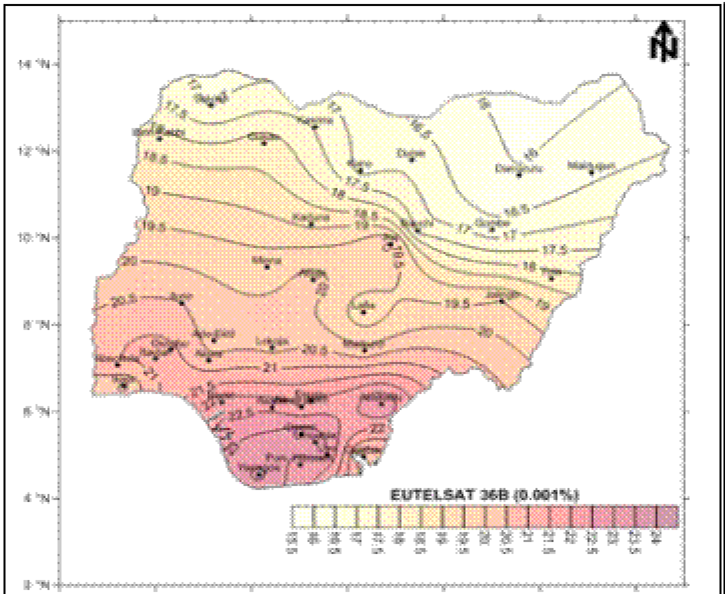

Fig. 4(f). Rain induced attenuation (dB) for digital satellite television reception on EUTELSAT 36B links over Nigeria at 0.001% of time

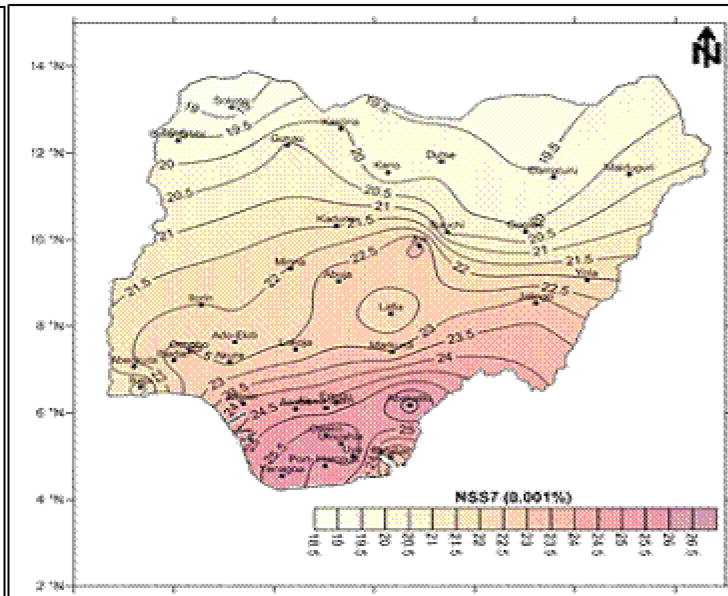

Fig. 4(h). Rain induced attenuation (dB) for digital satellite television reception on NSS7 links over Nigeria at 0.001% of time

INTELSAT 20 (geo-stationed at 68.5^{0}E) links. The prevailing effect of the high rainfall occurrence in the South-Southern parts is evidenced in the high attenuation observed over this region, across all the links between 0.001 – 1% of the time. The sites considered most vulnerable to rain attenuation across the six geopolitical zones and on each of the selected satellites are presented in Table 4.

5.1 Performance of the rain impaired reception

The performance of the digital television contents across the 37 TVRO systems was evaluated based on the E_b/N_0 at the input of the receiver. The received E_b/N_0 should ordinarily guarantee system availability for the enhanced content quality of the digital television received via satellite. The predicted E_b/N_o was compared with the reference threshold of 12 dB for 10^{-8} BER, considered for QPSK modulation for the DVB-S standard. The predicted E_b/N_0 for the sites considered most vulnerable to rain attenuation is shown in Figures 5 (a) – (c), while the least vulnerable sites are presented in Figures 5 (e) – (f) for 0.001 – 1% of the time.

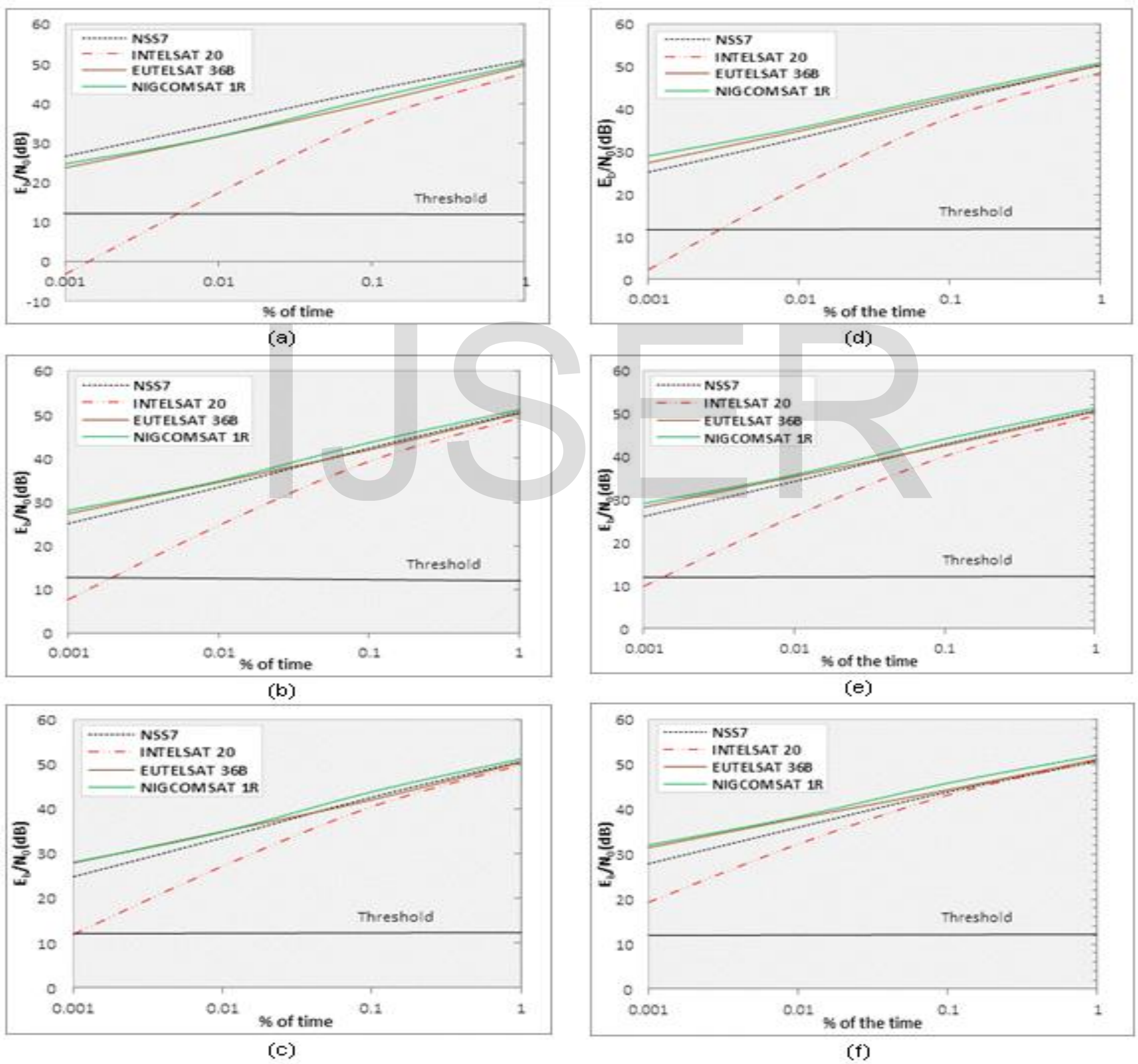

Fig. 5. Link performance at the receiver input of the most vulnerable sites to rain attenuation (a) Yenagoa, South-South, (b) Makurdi, Middle-Belt, (c) Jalingo, North-West, Nigeria

Fig. 5. Link performance at the receiver input of the least vulnerable sites to rain attenuation (d) Ikeja, South-West (e) Lafia, Middle-Belt, (f) Damaturu, North-East, Nigeria

TABLE 4.
SITES CONSIDERED MOST VULNERABLE TO RAIN ATTENUATION IN EACH GEOPOLITICAL ZONE ACROSS NIGERIA

Region	NIGCOMSAT 1-R	EUTELSAT 36B	INTELSAT 20	NSS 7
South-West	Ibadan	Ibadan	Abeokuta	Ibadan
South East	Abakaliki	Owerri	Owerri	Abakaliki
South-South	Yenagoa	Yenagoa	Yenagoa	Yenagoa
Middle-Belt	Makurdi	Ilorin	Ilorin	Makurdi
North-West	Kaduna	Kaduna	Kaduna	Kaduna
North-East	Jalingo	Jalingo	Jalingo	Jalingo

Results indicate good reception of the digital television signal at 0.01, 0.1 and 1% of the time, which is equivalent to 0.87, 8.7 and 87.6 hours respectively of an average year, when the E_b/N_o predicted is well above the 12dB reference threshold in all the locations over the 148 satellite to earth links. However, the E_b/N_o predicted at 0.001% (0.087 hours) indicate that 99.999% availability is not possible across the links. The worst performance is observed at Yenagoa (South-South) with a received E_b/N_o of 15 dB below the reference threshold of 12 dB.

6 CONCLUSION

In this paper, the performance of the digital satellite television has been evaluated under the influence of rain. Initial result from experimental campaign was used to investigate the performance of the digital satellite television reception due to the convective rain patterns over the measurement site. The point rain rate $R_{0.01}$ estimated from the cumulative rain rate statistics is 100 mm/h. Results reveal an abrupt squelching of the digital television signal around 64 mm/h – indicating the complete loss of the digital television content due rain.

Subsequent prediction over 148 different links produced varying rain attenuation estimates for the reception of digital television across the six geopolitical zones in Nigeria.

The system performance was evaluated based on the energy per bit to spectral noise density - E_b/N_0 required for optimal reception of the digital television content. Results indicate that good reception of the digital television content is possible across the links at 0.01, 0.1 and 1% of the time - 99.99, 99.9 and 99% link availability. However, the performance at 0.001% reveals the deficit fade margin required for 99.999% availability.

Although experimental measurement is still on-going at the measurement site, the results compared between the experimental and predicted rain attenuation estimates suggests that the typical user experience on the impairing effects of rain on digital satellite television reception is completely different from predictions.

However, there is the need to ascertain the suitability of the existing rain attenuation models and most importantly, develop a domestic rain attenuation model for planning links with optimal performance during rain occurrences.

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