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PERFORMANCE EVALUATION OF AN EMPIRICAL SITE DIVERSITY GAIN MODEL FOR SOUTH-SOUTH NIGERIA

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ABSTRACT

Site diversity is an effective technique to mitigate rain attenuation, especially in regions where rainfall rates are high. The South-South region of Nigeria is characterised by the tropical rain forest climate, exhibiting high rainfall rates almost all year round. This paper investigates site diversity gain in the South-South Nigeria at Ka-band frequencies of 20 GHz. Rainfall data obtained from the Nigerian Meteorological Agency (NIMET) over a period of five years for four selected earth stations (University of Uyo (UNIUYO), Uyo; Akwa Ibom International Airport (AKIA), Uyo; Margaret Ekpo International Airport (MEIA), Calabar; and Port Harcourt International Airport (PHIA), Port Harcourt) were analysed to derive a one-minute rainfall rate distribution. The link parameters of NigComSat-1R were incorporated with the International Telecommunication Union-Radiowave (ITU-R) model for rain attenuation to estimate the rain attenuation distribution through an annual cumulative distribution and percentage of outage time between 0.001 to 100 %. Site diversity was implemented. The results obtained from the analysis were used to develop a prediction model for site diversity gain using statistical and regression analysis based on the dependence of site diversity gain on other link parameters such as single site attenuation, site separation distance, operating frequency, elevation angle and baseline orientation angle. The proposed model when compared with the Hodge and ITU-R prediction models for site diversity gives a better performance, which may be quantified with root-mean-squared error values ranging from 0.22 to 1.71.

Keywords: Rain rate, rain attenuation, cumulative distribution, site diversity.

INTRODUCTION

Rainfall is the most severe cause of attenuation of electromagnetic waves of frequencies above 10 GHz (Yeo, Lee, and Ong, 2011). It constitutes one of the most fundamental limitations on the performance of communication links, giving rise to large variations in the received signal power (Arapoglou, Panagopoulos, Chatzarakis, Kanellopoulos, and Cottis, 2004; Yeo *et al*., 2011).

Strong propagation impairments have made it necessary to incorporate techniques which aim to mitigate the effects of propagation impairments such as rain attenuation in the design of telecommunication systems to operate at Ka and V-band frequencies. These techniques are referred to as fade mitigation techniques (FMTs). Some of these fades mitigation techniques have been proposed and are in existence (Semire, Ismail, Mohamad, and Mandeep, 2015). These include power control, adaptive-wave and diversity techniques. This research would dwell on a diversity technique known as site diversity (SD), which has been known to be more efficient (Arapoglou *et al*., 2004).

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Site diversity makes use of the spatial characteristics of the rainfall medium by using two or more earth stations to exploit the fact that the probability of attenuation due to rain occurring simultaneously on the various earth-space paths is significantly less than the relevant probability occurring on either individual path (Ippolito, 1999). The earth stations in a site diversity based communication system are geographically separated but terrestrially connected to each other, such that each site offers less correlated propagation paths between the earth station and the satellite. This technique links two or more earth stations receiving the same signal. The signal streams received at each station are sent to a named reference or base station, where these signal streams are processed using diversity combining techniques so as to improve its signal to noise ratio (SNR) (Semire *et al*., 2015). Hence, if the transmitted signal is severely impeded in one site, another earth station is used to compensate this effect.

REVIEW OF RELATED WORKS

A few of the most recent propagation studies on site diversity involving the Ku, Ka and V bands have been reported over the tropical region. In 2001, a study on site diversity performance was carried-out in Singapore (Timothy, Ong, and Choo, 2001). The research was carried out using a separation distance of 12.3 km and a non-conventional baseline orientation of 4^o. Two sites were employed in the research to implement SD. It was discovered that a link margin of 7 dB was exceeded at 0.02 % of time without SD during the observational period. However, when SD was deployed, the same level of attenuation was exceeded at 0.028 % of time. An improvement factor of 8 was achieved with the existing system specifications.

Otung and Nagaraja, (2009) conducted another study in South England, providing a detailed analysis of site diversity gain, as well as the spatial correlation of rain attenuation. This gave rise to an improved efficiency using site diversity for mitigating rain fade in the summer, and a larger sensitivity to baseline orientation in non-summer periods. Nagaraja and Otung, (2011) went ahead to propose an empirical model for statistical prediction of site diversity gain on earth-space propagation paths, incorporating 46 months of rain RADAR data in South England. The model performed with an overall root mean squared (RMS) error of 1.87 dB over varying link configurations with elevation angles ranging from 10^o to 50^o and transmission frequencies from 16 to 50 GHz.

In 2011, another experiment to evaluate micro scale site diversity was conducted in Ahmedabad, a tropical site in India (Roy, Shukla, and Sivaraman, 2011). An attenuation of 30 GHz signal was estimated using synthetic storm technique and was used to obtain site diversity gain.

Furthermore, an analysis on weather radar and beacon data for the simulation and performance of site diversity technique was performed in South-East Asia (Semire, Mohd-mokhtar, Ismail, Mohamad, and Mandeep, 2014). The authors examined the effects of site separation distance, elevation angle, frequency of operation and baseline angle on site diversity. It was discovered that site diversity gain depends greatly on site separation distance and elevation angle and it is less dependent on frequency and baseline angle of the site diverse stations. Also, comparative studies were carried out which have shown that all three existing models that were considered in the work underestimates site diversity gain at all separation distances except the Hodge model, which underestimates site diversity gain at a site separation distance of 10 km and above. In 2015, Semire et al went ahead to present an empirical model for long-term rain attenuation prediction as well as statistical prediction of site diversity gain on a slant path. The proposed model exhibited a reasonable reduction in prediction error in terms of standard deviation and RMS error. The model included low elevation angles and high frequency up to 70 GHz in its derivation, the overall performance provided a percentage error within the allowable error limit approved by the ITU-R.

DESCRIPTION OF THE RAINFALL DATA

Rainfall data for AKIA, MEIA and PHIA were obtained from NIMET and for UNIUYO from the University of Uyo weather station for a period spanning over five years respectively. The rainfall accumulation data retrieved from both database, show daily rainfall volume (measured in mm), obtained using tipping bucket rain gauges. Monthly and annual rainfall accumulations were extracted from the rainfall data. Mean annual rainfall accumulations were obtained over five years for each station. A summary of the rainfall data obtained for each site is presented in Table 1.

Table 1: Statistics of rainfall accumulation for the study area over a period of five years

	ANNUAL RAINFALL ACCUMULATION (mm)			
Year	UNIUYO	AKIA	MEIA	PHIA
2010	2848.8	3172.8	3071.5	2837.0
2011	2930.9	3968.8	3487.2	2049.9
2012	3835.1	4651.0	4070.7	2842.2
2013	2867.5	4494.1	3506.4	2513.2
2014	3027.7	4267.8	3286.9	2322.4
Average	3102.0	4110.9	3484.5	2512.9

RAIN RATE AND RAIN ATTENUATION DISTRIBUTION

This research employs the Chebil rain rate model (Chebil and Rahman, 1999) and the Moupfouma model for rainfall distribution (Moupfouma, 2009) to derive the one minute rainfall distribution for the region under study. The Chebil and Rahman (1999) rain rate model allows for the usage of mean annual long-term rainfall accumulation M to compute the point rainfall rate $R_{0.01}$, for the location under study. This model uses the power law relationship expressed as:

$$R_{0.01} = \alpha M^{\beta} \quad (1)$$

where $\alpha = 12.2903$ and $\beta = 0.2973$ are regression coefficients

The Moupfouma and Martins, (1995) model has been suggested from recent analysis to be good for both tropical and temperate regions (Ojo *et al*., 2008). According to Moupfouma, (2009), one-minute rain rate cumulative distribution is the probability $P(R \geq r)$ that one minute rainfall intensity R (mm/hr) exceeds a threshold value $r\,(\mathrm{mm/hr})$ for a fraction of time. The model is expressed as:

$$P(R \geq r) = 10^4 \left(\frac{R_{0.01}}{r+1}\right)^b \exp(\mu[R_{0.01} - r]) \quad (2)$$

where μ governs the slope of the rain rate cumulative distribution and depends on the local climatic conditions and geographical features.

For the tropical and sub-tropical regions, μ and b are approximated using the Equations (3) and (4).

$$\mu = \frac{4\ln 10}{R_{0.01}} \exp\left(-\lambda \left[\frac{r}{R_{0.01}}\right]^{\gamma}\right) \quad (3)$$

where $\lambda = 1.066$ and $\gamma = 0.214$

$$b = \left(\frac{r - R_{0.01}}{R_{0.01}}\right) \ln\left(1 + \frac{r}{R_{0.01}}\right) \quad (4)$$

Thus, the Moupfouma model requires three input parameters; λ, γ, and $R_{0.01}$. The first two parameters have been provided. When estimating $R_{0.01}$, the Chebil's model becomes suitable (Isikwe *et al*. 2013; Ojo *et al*. 2008). The rainfall accumulation statistics that were obtained were incorporated with the Chebil and refined Moupfouma models for converting the available rainfall data to the equivalent one minute rain rate cumulative distribution.

The rain attenuation was computed using the ITU-R model (ITU-R 2015) which is widely accepted for the prediction of rain attenuation (Yussuff and Hisham, 2012). The ITU-R model is semi-empirical and often employs the local climatic parameters at a desired probability of exceedance (Malinga, Owolawi, and Afullo, 2013). The input local climatic parameters include: point rainfall rate for 0.01 % of an average year ($R_{0.01}$) in mm/hr; height above sea level of the earth station (H) in km; elevation angle (θ) in degrees; latitude of the earth station ($\emptyset$) in degrees; operating frequency (f) in gigahertz and effective radius of the earth (R_e) in kilometres. The cumulative distributions of rain attenuation were obtained at a Ka band frequency of 20 GHz and a NIGCOMSAT 1-R orbital position of 42.5°, other earth station parameters are summarized in Table 2.

Table 2: Earth- station parameters

Parameters	AKIA	MEIA	PHIA	UNIUYO
Longitude (°E)	8.085736	8.346960	6.950289	7.918825
Height above sea level (m)	51.2	62.3	29.0	66.0
Distance from Satellite (km)	37099.40	37082.02	37182.87	37175.40
Elevation angle (degrees)	49.67	49.94	48.38	48.49
Azimuth (degrees)	97.08	97.08°	96.97	96.98

SITE DIVERSITY IMPLEMENTATION

An implementation of the site diversity technique requires the parameters known as joint site attenuation and site diversity gain to be computed. Joint site attenuation is the minimum attenuation between the instantaneous rain attenuations of the reference site and the diversity site (Otung and Enoch, 2011). It is obtained using a joint attenuation time series A_j, (dB) as follows:

$$A_{Jref,i} = \min[A_{ref}(t), A_i(t)] \quad (5)$$

Where $A_{ref}(t)$ and $A_i(t)$ are the instantaneous rain attenuation values at the reference and diversity stations respectively (i = 1,2,3,……n, n being the number of diversity stations).
This link performance is usually measured using the site diversity gain. SD gain is the difference in link attenuation for a given percentage of time between the single link A(dB), (single site attenuation) and the joint site diversity configuration A_j(dB), (joint site attenuation) (Hendrantoro, Bultitude, and Falconer, 2002; Otung and Enoch, 2011).

$$G_{SD} = A_i - A_{jref,i} \quad (6)$$

Joint site attenuation was computed with UNIUYO taken as the reference site; this was done by computing the minimum instantaneous values of rain attenuation between UNIUYO and each other site (using the rain attenuation distribution obtained for each site). A program was written in MATLAB to implement the joint attenuation in each case. A cumulative distribution function (CDF) was plotted for the single site attenuation and the joint site attenuation. The values that were obtained at 0.01 % of time and 20 GHz frequency are 48.92 dB, 49.29 dB and 45.33 dB with diversity sites taken as AKIA, MEIA and PHIA respectively. Site diversity gain was determined for the three cases of joint attenuation that had been obtained, and CDFs were plotted. The values of gain obtained at 0.01 % of time and at 20 GHz are 1.37 dB, 1.00 dB and 4.96 dB with diversity sites taken as AKIA, MEIA and PHIA respectively.

PROPOSED SD MODEL

The proposed site diversity model is a modification of the Hodge and ITU-R model (Hodge 1982; ITU-R 2015) to be adaptable to the study area. It was derived based on the rain attenuation measurements from four sites (UNIUYO, AKIA, MEIA and PHIA). A regression analysis was carried out and a fitting was obtained on the numerical values derived from rain attenuation and site diversity measurements in the previous sections. Site diversity gain was modelled as a function of five (5) major link parameters (single site attenuation A_s, site separation distance d, elevation angle θ, frequency of operation f, and baseline orientation ψ). In the modelling of SD gain as a function of site separation distance, distances between the reference earth station and the diversity earth stations were obtained using the haversine formula (21.1 km, 48.2 km and 117.3 km between UNIUYO and AKIA, MEIA and PHIA respectively). Data values of site diversity gain were regressed with respect to the values of single site attenuation, A_s at different time percentages and at a frequency of 20 GHz using the exponential relation of the form:

$$G_D = a\left(1 - e^{-bA_s}\right) \quad (7)$$

The regression fit of SD gain as a function of A_s for the three sites are shown in Figures 1, 2 and 3.

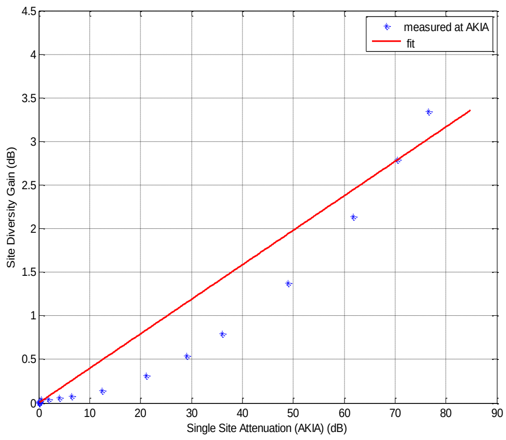

Figure 1: Regression fit of diversity gain as function of single site attenuation measured at AKIA

The coefficients a and b, were obtained with sum of squared errors (SSE) ranging from 0.0295 to 2.613, R-squared (R^2) ranging from 0.9189 to 0.9998, and root-mean-squared error (RMSE) ranging from 0.04048 to 0.381. Table 3 shows the values of coefficients a and b obtained for the three diversity sites.

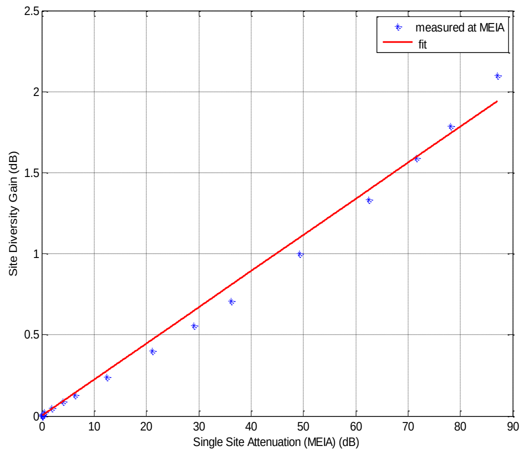

Figure 2: Regression fit of diversity gain as function of single site attenuation measured at MEIA

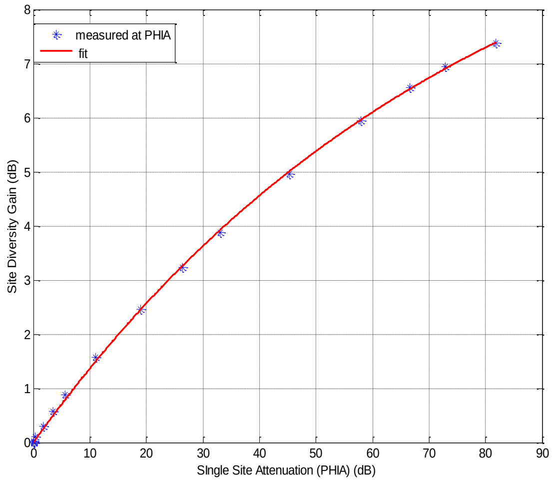

Figure 3: Regression fit of diversity gain as function of single site attenuation measured at PHIA

Table 3: Coefficients of regression for single site attenuation dependence

Stations	A	B
AKIA	6.7859	0.0127
MEIA	7.5970	0.0045
PHIA	11.4100	0.0128

Further regression analysis was done to determine the set of equations that define the regression coefficients, a and b. This was obtained from a regression fit of a and b respectively, as functions of site separation distances of the diversity stations from the reference station based on the exponential equation of the form:

$$a = a_o e^{a_1 d} \quad (8)$$
$$b = b_o e^{b_1 d} \quad (9)$$

Operating frequency was kept constant at 20 GHz. The elevation angle and baseline orientation angle were kept at 45^o and 48^o respectively. The regression fit of a and b as functions of d, are shown in Figures 4 and 5 respectively. The coefficients a_o, a_1, b_o, and b_1

were obtained with SSE ranging from 4.25×10^{-5} to 0.06488, R^2 ranging from 0.0631 to 0.9947, and RMSE ranging from 0.0065 to 0.2547.

The regression coefficients are: $a_o = 5.9480$; $a_1 = 0.0054$; $b_o = 0.008491$; and $b_1 = 0.002482$. Hence, inputting the values for a_o, a_1, b_o and b_1 in Equations (8) and (9), yields:

$$a = 5.948e^{0.0054d} \tag{10}$$
$$b = 0.008491e^{0.002482d} \tag{11}$$

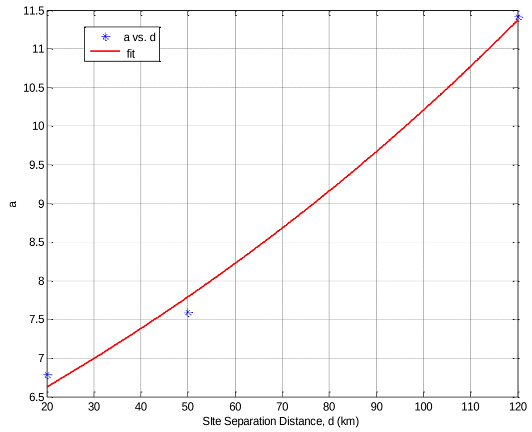

Figure 4: Regression line of fit for coefficient a

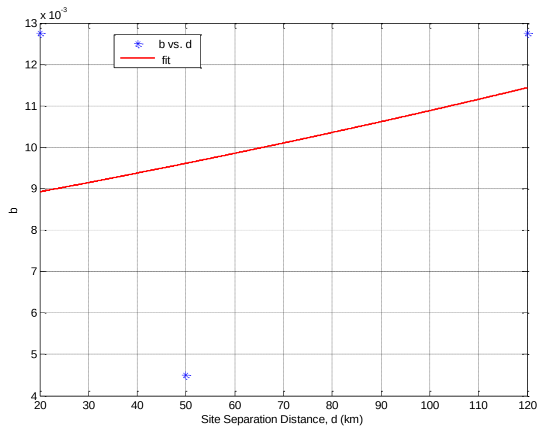

Figure 5: Regression line of fit for coefficient b

The model of SD gain with respect to operating frequency was derived with other link parameters kept constant (d = 60 km, A_s = 50 dB, $\theta = 45^o$ and $\psi = 85^o$). It was observed that the regression fit of SD gain varies exponentially with frequency. The relationship is described by the Equation 12.

$$G_f = xe^{yf} \tag{12}$$

The regression coefficients x and y are given as, $x = 1.2140$ and $y = 0.01269$
SD gain dependence on elevation angle was determined using the same procedure as obtained for frequency dependence. This was carried out at a frequency of 20 GHz with other link parameters held at the same previous values. The regression fit shows a linear relationship described by Equation (13):

$$G_\theta = P_1\theta - P_2 \tag{13}$$

The regression coefficients P_1 = 0.1425 and P_2 = 5.8420.
The dependence on baseline orientation was determined at a frequency of 20 GHz and an elevation angle of 45^o, other parameters were kept at same constant level. A linear relationship was also observed to exist between SD gain and baseline orientation. It is described by Equation (14):

$$G_\psi = b_1 - b_2\psi \tag{14}$$

Where b_1 = 7.206 and b_2 = 0.07298
The regression fits of SD gain as functions of frequency, elevation angle and baseline orientation were obtained at RMSE ranges below 0.25. The model is expressed as

$$G(A_s, d, f, \theta, \psi) = G_{A_s} G_d G_f G_\theta G_\psi \tag{15}$$

If A_s and d are functions of D, then

$$G(D, f, \theta, \psi) = G_D G_f G_\theta G_\psi \tag{16}$$

Where:

$$G_D = a\left(1 - e^{-bA_s}\right)$$

$$G_f = 1.1214e^{0.01269f} \tag{17}$$

$$G_\theta = 0.1425\theta - 5.842 \tag{18}$$

$$G_\psi = 7.206 - 0.07298\psi \tag{19}$$

a and b are given by Equations (10) and (11).

The performance of the proposed model was tested with existing SD prediction models and the accuracy was examined using the RMS error and the relative SD error in percentage.

PERFORMANCE EVALUATION OF THE PROPOSED MODEL

The proposed site diversity model was compared to the experimental results to determine its level of accuracy. This was done by inputting the various site parameters of each diversity earth station into the mathematical expressions of the proposed model, the results obtained were plotted alongside the experimental results for each site.
The compliance of the proposed model with the measured results was determined using the percentage error (ε) given as:

$$\varepsilon(p) = 100[g_{est}(p) - g_{mea}(p)] \tag{20}$$

$g_{est}(p)$ and $g_{mea}(p)$ are the predicted and measured relative gains respectively for a given probability (Ippolito 1999).
Relative diversity gain (g) is described as the ratio of the diversity gain (G_{SD}) and the corresponding single site attenuation (A_i) of the main station (Marina, Ermanno, Ondrej, Antonio, Frank, Peter and Wrench., 2010). The relative gain is expressed as

$$g = \frac{G_{SD}}{A_i} \tag{21}$$

The proposed model was compared with other existing SD models such as the Hodge and ITU-R. The RMSE was computed as the difference between the estimated (predicted) and the measured SD gains (G_{est} and G_{mea}) for 20 time percentages (from 0.001 % to 1 %) using Equation 22.

$$RMSE = \sqrt{\frac{\sum\left(\frac{G_{est}-G_{mea}}{G_{mea}}\right)^2}{20}} \qquad (22)$$

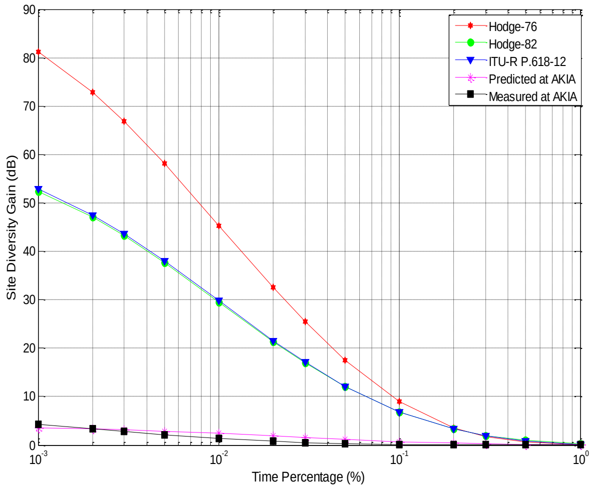

Figure 6: Performance evaluation of existing models in comparison with measured data and predicted model at AKIA

Figures 6, 7 and 8 show the comparison of the predicted model with other existing SD models (Hodge-1976, Hodge-1982 and ITU-R P.618-12) at the three diversity earth stations.

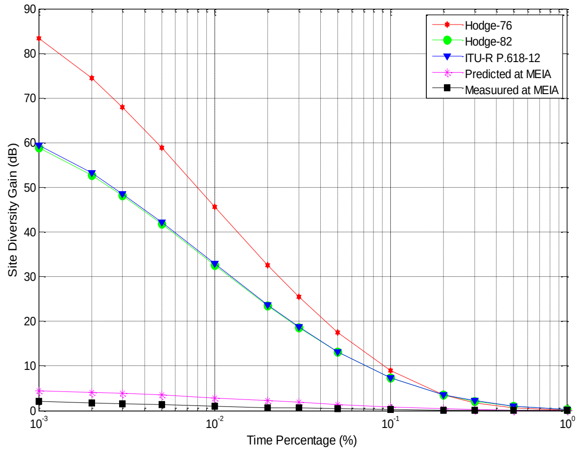

Figure 7: Performance evaluation of existing models in comparison with measured data and predicted model at MEIA

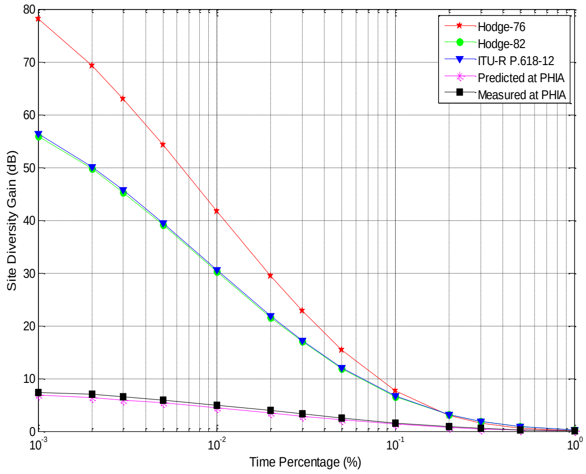

Figure 8: Performance evaluation of existing models in comparison with measured data and predicted model at PHIA

It was observed that the prediction models are in agreement at time percentages above 0.5 %. However, a deviation was observed at time percentages below 0.5 % of outage time. The other SD prediction models (Hodge-76, Hodge-82 and ITU-R) therefore, overestimate SD gain for this region at percentages of time below 0.5 %. The possible reasons for this overestimation include:

i. Predictions were carried out using rainfall statistics from other regions that may possess different rainfall characteristics of this study area;
ii. Predictions were carried out at frequency ranges in the Ku-band where rain attenuation is less severe; and
iii. Predictions were done at site separation distances less than or equal to 20 km.

In order to estimate the accuracy of the proposed model, the percentage errors and RMS errors presented by the models are summarised in Table 4.

Table 4: Performance evaluation of SD gain prediction models at 0.01 % of time

	AKIA		MEIA		PHIA	
SD prediction models	RMSE	ε (%)	RMSE	ε (%)	RMSE	ε (%)
Proposed model	1.7122	1.9672	1.5875	3.7779	0.2233	0.8951
Hodge model-1976	29.2137	87.3746	29.2927	88.8567	5.0050	73.1167
Hodge model-1982	22.2562	55.9856	22.5337	62.8929	3.5782	50.2577
ITU-R model (P.618-12)	22.2860	56.5042	22.5808	63.4792	3.6060	50.7990

It can be seen that the errors have been significantly reduced with the proposed model; the estimated RMS error range is between 0.22 and 1.7 while the relative error lies below 2 %. The 1976 Hodge model presented the highest RMS error of 29.29 in MEIA, and the relative diversity error between 73.11 and 88.85 %. This shows that the proposed model can better predict SD gain for this region.

CONCLUSION

Rainfall data obtained from NIMET for five years (2010 - 2014) have been used to evaluate the effects of factors that may affect the performance of SD technique in South-South Nigeria. The proposed model shows that SD gain is much more dependent on site separation distance. The SD gain obtained for PHIA is highest; however PHIA is sited farthest from the reference station (UNIUYO).

The contribution to knowledge lies in the modification of the Hodge's ITU-R model for estimating the SD gain, based on rainfall measurements at 20/30 GHz links in South-South Nigeria. The proposed prediction model presents results which are comparable to the measured site diversity gain for the South-South Nigeria. The validation of the new SD prediction model was carried-out using the single site attenuation at the stations, while its performance was evaluated through comparing it with three (3) other existing SD models. The RMSE lies within allowable limits as determined by the ITU-R 618 recommendation. It is expected that the model would provide a good and relatively accurate means for predicting SD gain. This should substantially reduce the time and cost for designing and implementing an earth-space link system in this region.

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REFERENCES

Arapoglou, P. D. M., Panagopoulos, A. D., Chatzarakis, G. E., Kanellopoulos, J. D., and Cottis, P. G. (2004). Diversity Techniques for Satellite Communications: An Educational Graphical Tool. *IEEE Antennas and Propagation Magazine*, *46*(3), 109–114.

Chebil, J. and Rahman, T. A.(1999). Rain Rate Statistics Conversion for Prediction of Rain Attenuation in Malaysia. *Electromagnetic Letters*, 35, 1019-1999.

Hendrantoro, G., Bultitude, R. J. C., and Falconer, D. D. (2002). Use of Cell-Site Diversity in Millimeter-Wave Fixed Cellular Systems to Combat the Effects of Rain Attenuation. *IEEE Journal Of Selected Areas in Communications*, *20*(3), 602–614.

Hodge, D. B. (1982). An Improved Model for Diversity Gain on Earth-Space Propagation Paths. *Radio Science*, *17*(6), 1393–1399.

Ippolito, L. J. (1999). Propagation Effects Handbook for Satellite Systems Design - Section 2. *Jet Propulsion*,

Isikwe, B. C., Ikoyo, A. H., and Utah, E. U. (2013). Analysis of Rainfall Rates and Attenuations for Line – of – Sight EHF / SHF Radio Communication Links Over Makurdi , Nigeria. *Research Journal of Earth and Planetary Sciences*, *3*, 60–74.

ITU-R. (2015). Propagation Data and Prediction Methods Required for the Design of Earth-Space Telecommunication Systems. *Recommendation ITU-R P.618-12*, *P Series Radiowave Propagation*, 12.

Malinga, S. J., Owolawi, P. A., and Afullo, T. J. O. (2013). Estimation of Rain Attenuation at C , Ka , Ku and V Bands for Satellite Links in South Africa. *PIERS Proceedings, Taipei*, 948–958.

Marina, B. C., Ermanno, F., Ondrej, F., Antonio, M., Frank, S. M., Peter, W., and Wrench, C. (2010). PART 2 Fixed Propagation Modelling Propagation Effects due to Atmospheric Gases and Clouds. In *COST*.

Moupfouma, F. and Martin, S.,(1995). Modelling of Rainfall Rate Cumulative Distribution for Design of Satellite and Terrestrial Communication Systems. *International Journal of Satellite Communication*, 13(2) 105-115.

Moupfouma, F (2009). Electromagnetic Wave Attenuation due to Rain. A Prediction Model for Terrestrial L.O.S SHF/EHF Radio Communication Links. *Journal of Infrared Milli Tetrahertz Waves.* 30(3):622-632.

Nagaraja, C., and Otung, I. E. (2011). Statistical Prediction of Site Diversity Gain on Earth-Space Paths based on Radar Measurements in the UK. *IEEE, 1*(c), 12–15.

Ojo, J. S., Ajewole, M. O., and Sarkar, S. K. (2008). Rain Rate and Rain Attenuation Prediction for Satellite Communication in Ku and Ka Bands over Nigeria. *Progress in Electromagnetics Research*, *5*, 207–223.

Otung, I. E., and Enoch, S. (2011). Mitigation of Rain Attenuation in Fixed WiMAX using Cell Site Diversity. *Electronics*, *47*(5), 49–50.

Otung, I. E., and Nagaraja, C. (2009). Seasonal Variation of Site Diversity Performance. *Electronic Letters*, *45*(14), 9–10.

Roy, B., Shukla, A. K., & Sivaraman, M. R. (2011). Micro Scale Site Diversity over a Tropical Site in India and Evaluation of Diversity Gain with Synthetic Storm Technique. *Indian Journal of Radio and Space Physics*, *40*(8), 211–217.

Semire, F. A., Ismail, W., Mohamad, N., and Mandeep, J. S. (2015). Modeling of Rain Attenuation and Site Diversity Predictions for Tropical Regions. *Annales Geophysicae, 33*(3), 321–331.

Semire, F. A., Mohd-mokhtar, R., Ismail, W., Mohamad, N. and Mandeep, J. S. (2014). Evaluation of Site Diversity Rain Attenuation Mitigation Technique in South-East Asia. *Acta Astronautica*, *96*(4), 303–312.

Timothy, K. I., Ong, J. T., Choo, E. B. L., Timothy, K. I., Ong, J. T., and Choo, E. B. L. (2001). Performance of the Site Diversity Technique in Singapore: Preliminary Results. *IEEE Communications Letters*, *5*(2), 49–51.

Yeo, J. X., Lee, Y. H., and Ong, J. T. (2011). Performance of Site Diversity Investigated Through RADAR Derived Results. *IEEE Transactions on Antennas and Propagation*, *59*(10), 1–9.

Yussuff, A. I. O., and Hisham, N. Aji K. (2012). Rain Attenuation Modelling and Mitigation in The Tropics : Brief Review. *International Journal of Electrical and Computer Engineering (IJECE)*, *2*(6), 748–757.