International Journal of Information and Communication Sciences
2016; 1(3): 54-58
http://www.sciencepublishinggroup.com/j/ijics
doi: 10.11648/j.ijics.20160103.14

Seasonal Variations of Site Diversity Along Earth-Space Paths in Nigeria

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To cite this article:
Achor Jane O., Udofia Kufre M., Obot Akaninyene B. Seasonal Variations of Site Diversity Along Earth-Space Paths in Nigeria. *International Journal of Information and Communication Sciences.* Vol. 1, No. 3, 2016, pp. 54-58. doi: 10.11648/j.ijics.20160103.14

Received: October 16, 2016; **Accepted**: December 28, 2016; **Published**: January 16, 2017

Abstract: Site diversity (SD) is an effective technique for mitigating rain attenuation in satellite communications, especially in regions where rainfall rates are high. Nigeria is characterised by the tropical climate, this implies that rainfall rates are generally high. This paper presents a study of the seasonal variation of site diversity technique in Nigeria at Ka-band frequency of 20 GHz. Rainfall data obtained from the Nigerian Meteorological Agency (NIMET) over a period of five years (2010 to 2014) were analysed to derive the one-minute rainfall rate distribution for four selected earth stations (University of Uyo, Uyo (UNIUYO); Akwa Ibom International Airport, Uyo (AKIA); Margaret Ekpo International Airport, Calabar (MEIA); and Port Harcourt International Airport, Port Harcourt (PHIA)) within the South-South Nigeria. The link parameters of Nigerian Communication Sattelite-1R (NigComSat-1R) were incorporated into the ITU-R model for rain attenuation to estimate the rain attenuation distribution through a seasonal cumulative distribution and percentage of outage time between 0.01 to 100%. Site diversity was implemented, taking University of Uyo as the reference site. The results obtained show that SD technique is most effective between the months of March and May and least effective between September and December.

Keywords: Rain Rate, Rain Attenuation, Cumulative Distribution, Site Diversity

1. Introduction

Rainfall is the most severe cause of attenuation of electromagnetic waves at frequencies above 10 GHz [1]. It constitutes one of the most fundamental limitations on the performance of radio communication links, giving rise to large variations in the received signal power [1, 2].

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 that operate at Ka and V-band frequencies. These techniques are referred to as fade mitigation techniques (FMTs). Some of these fade mitigation techniques have been proposed and are in existence [3]. 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 [2].

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 [4]. 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 stations 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) [3]. Hence, if the transmitted signal is severely impeded in one site, another earth station is used to compensate this effect.

This paper presents the seasonal variations of site diversity technique along earth-space paths in Nigeria. This was achieved through analysis of rain attenuation experienced in each season.

2. The Nigerian Climate and Rainfall Distribution

Nigeria is characterized by the tropical climate; this implies that the rain rates are generally high. The precipitation characteristics in the tropics differ appreciably from those of the temperate region. Tropical rainfall has been shown to be predominantly convective and characterized by high precipitation rates [5]. The climate in Nigeria exhibits two major seasons, they are: the rainy season (which spans from April to October) and the dry season (which spans from November to March). For this research, the Nigerian climate was classified into:

A. Intense dry season (very low rain intensity), spanning from December to February;
B. Slightly dry season (more dry than rainy), spanning from March to May;
C. Intense rainy season (very high rain intensity), spanning from June to August; and
D. Slightly rainy season (more rainy than dry), spanning from September to November.

Cumulative rainfall volumes were obtained from four selected sites according to these seasons (A, B, C, D) and over a period of five years (2010 to 2014). Table 1 shows the average annual rainfall accumulation for each season.

Table 1. *Average Annual Rainfall Accumulation According To Seasons.*

Site	A (Dec – Feb) Average Cumulative Rainfall Volume (mm)	B (Mar – May) Average Cumulative Rainfall Volume (mm)	C (Jun – Aug) Average Cumulative Rainfall Volume (mm)	D (Sep – Nov) Average Cumulative Rainfall Volume (mm)
AKIA	1073.30	2171.50	8206.20	4992.20
MEIA	1224.00	3679.20	7602.50	4917.00
PHIA	668.70	2879.40	4940.90	4104.70
UNIUYO	998.20	3174.30	6713.90	4970.10

Analyses were carried out based on these sub-divisions to determine the seasonal variations of site diversity gain. This was done in stages: these involve the calculation of the seasonal rain rate and rain attenuation for each site, the joint attenuation was computed and the site diversity gain for each season was derived.

3. Seasonal Rain Rate and Rain Attenuation

The dependence of rain attenuation on the intensity of rainfall in a region implies that attenuation varies along seasons due to the uneven distribution of rainfall throughout the year, giving rise to seasonal variations in SD gain.

This research uses of the Chebil rain rate model [6] and the Moupfouma model for rainfall distribution [7] to derive the one minute rainfall distribution for the region under study. The Chebil rain rate model allows for the usage of long-term mean annual rainfall accumulation M to compute the point rainfall rate R0.01, for the location of interest. This model uses the power law relationship expressed as:

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

where α and β are regression coefficients defined as:

$\alpha = 12.2903$ and $\beta = 0.2973$

The Moupfouma and Martins, [8] model has been suggested from recent analysis to be good for both tropical and temperate regions [9]. According to Moupfouma, [7], 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 (mm/hr) for a fraction of time. The Moupfouma 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: R0.01 (mm/hr) is the rain rate exceeded at 0.01 percent of time in an average year, r (mm/hr) represents the rain rate exceeded for a fraction of time, μ and b govern the slope of the rain rate cumulative distribution and depend 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 [9, 10].

The rainfall accumulation statistics that were obtained were incorporated into the Chebil and refined Moupfouma models for converting the available rainfall data to the equivalent one minute rain rate cumulative distribution. Table 2 shows the seasonal rainfall rates obtained for each season at 0.01% of outage time.

Table 2. *Seasonal Rainfall Rates At 0.01% Outage Time.*

Sites	A (Dec – Feb) Rainfall Rates (mm/hr)	B (Mar – May) Rainfall Rates (mm/hr)	C (Jun – Aug) Rainfall Rates (mm/hr)	D (Sep – Nov) Rainfall Rates (mm/hr)
AKIA	97.86	120.67	179.16	154.55
MEIA	101.76	141.14	175.13	153.85
PHIA	85.02	131.22	154.07	145.81
UNIUYO	95.77	135.08	168.78	154.34

The rain attenuation was computed using the ITU-R model [11] which is widely accepted for the prediction of rain attenuation [12]. The ITU-R model is semi-empirical and often employs the local climatic parameters at a desired probability of exceedance [13]. The input local climatic parameters include: point rainfall rate for 0.01% of an average year (R0.01) 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 (Re) 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 42.5o, other earth station parameters are summarized in Table 3.

Cumulative distribution functions (CDFs) were plotted to show the seasonal variations of rain attenuation. Table 4 shows the rain attenuation values obtained for each season at 20 GHz and 0.01% time of an average year.

Table 3. *Earth-Station Parameters.*

Parameters	AKIA	MEIA	PHIA	UNIUYO
Longitude (oE)	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	97.08o	96.97	96.98

Table 4. *Seasonal Variations Of Rain Attenuation At 0.01% Of Outage Time.*

Seasons	UNIUYO Rain Attenuation (dB)	AKIA Rain Attenuation (dB)	MEIA Rain Attenuation (dB)	PHIA Rain Attenuation (dB)
A (Dec – Feb)	39.71	39.34	41.00	37.09
B (Mar –May)	48.69	44.59	49.70	48.09
C (Jun – Aug)	55.27	55.89	56.15	52.73
D (Sep – Nov)	52.55	51.44	50.63	51.09

4. Seasonal Joint Site Attenuation and SD Gain

The implementation of 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 [14]. It is obtained using a joint attenuation time series Aj, (dB) as follows:

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

where: Aref(t) and Ai(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 Aj(dB), (joint site attenuation) [14, 15].

$$G_{SD} = A_i - A_{jref,i} \tag{6}$$

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). CDFs were plotted for the single site attenuation and the joint site attenuation. Table 5 shows the joint site attenuation obtained at 0.01% of outage time.

Site diversity gain was computed for each season and CDFs were plotted to show the variations. The values of single site attenuation and joint site attenuation were inputted into Equation (6) to derive the values of SD gain. Table 6 shows the values obtained for each season at 0.01%.

Table 5. *Seasonal Joint Site Attenuation.*

Seasons	Joint site Attenuation (dB)
A (Dec – Feb)	37.09
B (Mar – May)	44.59
C (Jun – Aug)	52.73
D (Sep – Nov)	50.63

Table 6. *Seasonal SD Gain.*

Seasons	Site Diversity Gain (dB)
A (Dec – Feb)	2.62
B (Mar – May)	4.10
C (Jun – Aug)	2.54
D (Sep – Nov)	1.62

5. Results and Discussion

The seasonal variation of rain rate and rain attenuation has shown a very high level of rain rate, which corresponds to relatively high levels of rain attenuation between the months of June and August, ranging from 52.73 dB to 55.89 dB at 0.01% unavailability. The magnitude of rain attenuation decreased slightly between September and November, ranging from 50.63 dB to 52.55 dB, further decline was observed between March and May (44.59 dB to 49.70 dB) and December to February (37.09 dB to 39.72 dB). Figure 1 shows the CDFs of rain attenuation for each season.

The cumulative distribution of the joint site attenuation is shown in Figure 2a. The highest joint rain attenuation values were observed between the months of June to August, while the lowest were observed between the months of December to February. The cumulative distribution of site diversity gain in Figure 2b shows the SD gain to be highest in the months March to May, while the least gain is observed between September and November. This is an indication that rain attenuation experienced between the reference site and the diversity site is largely uncorrelated between March and May. Other stations, however, experience higher levels of correlation in rain attenuation between the reference and diversity sites.

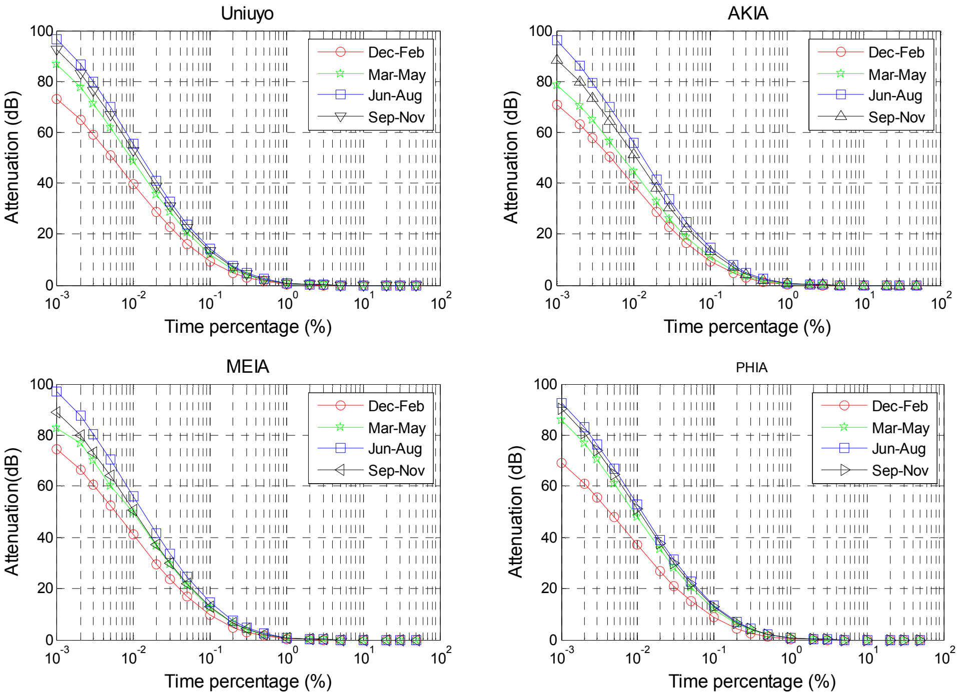

Figure 1. *Cumulative Distribution Of Seasonal Rain Attenuation.*

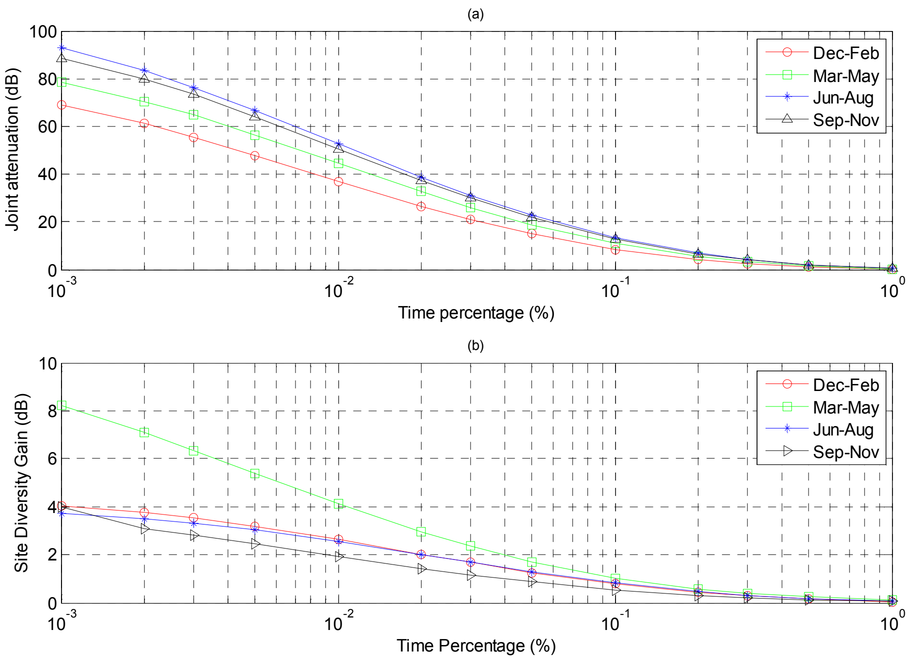

Figure 2. *Cumulative Distribution Of (A) Seasonal Variation Of Joint Site Attenuation and (B) Seasonal Variation Of SD Gain.*

6. Conclusion

The seasonal variations of SD performance in Nigeria have shown that a considerable improvement in link margin is attainable in satellite communications despite the very high rate of rain attenuation. Furthermore, it was observed that SD technique exhibits significant seasonal variation, with increasing SD gain as the instantaneous correlation of rain attenuation decreases. SD technique has been observed to be most efficient between March and May making it more effective in mitigating rain attenuation, especially when it is configured with more diversity earth stations. However, SD technique has been observed to be least efficient between September and November, other fade mitigation techniques could be employed during this season.

Acknowledgements

The authors are grateful to the Management of the Nigerian Meteorological Agency (NIMET), Margaret Ekpo International Airport, Calabar, Cross River State and the University of Uyo Weather Station for allowing access to the data used in this research work.

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