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Prediction Model for GSM Signal Attenuation in the Abis Interface during Heavy Rainfall in Nigeria

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Abstract

Measurement of Received Signal Levels (RSL) at 13GHz and 15GHz frequencies of Airtel (Nig) ltd GSM Network Microwave link in the A_{bis} interface were obtained for a period of two years on clear sky and during rainfall events. The analysis of the measured RSL with the link document was used to determine the link worst faded signal during heavy rainfall. The measured RSL based on the link performance analysis were used to determine the rain induced attenuation and it was developed in to empirical models with the extracted rain rate obtained from the Nigerian Meteorological Agency (NIMET). The developed models have mean model error of 0.0019 and a standard deviation of 0.0043 at 13GHz. While at 15GHz the mean model error and standard deviation were 0.0108 and 0.0245 respectively. These predictions showed that the ITU-R model under estimated rain induced attenuation at 0.1% and 0.01% time of the year. It also suggested compensation factors of 11.35dB at 13GHz and 18.78dB at 15GHz to be added to the link path loss.

Keywords: GSM, A_{bis} Interface; Faded RSL and Attenuation

1. Introduction

Microwave links are used extensively for base station backhaul in the base station subsystem of mobile communication network of GSM in Nigeria. At present, more than 60% of all base stations are connected via microwave links because the majority of operators seek to minimize their operating expenses (OPEX) by owning their own transport networks instead of leasing capacity. These communication links being used in the "A_{bis}" interface of the GSM architecture by Airtel (Nig) ltd at Kaduna-Nigeria operate at frequencies above

10GHz. Kaduna State is located in the North West zone in Nigeria on latitude 100.31'N and longitude 70.26'E. The utilization of this higher frequency band provides a number of important benefits, it relieves the congestion in the lower frequency bands and it also exploits the larger bandwidths available at higher frequencies so as to accommodate the high demands for broadband services [2].

Despite the advantages suggested by the use of these frequency bands, the systems can be easily degraded by some natural atmospheric phenomena of which rain is the principal factor and needs to be appropriately quantified so as to enhance reliable communication [1]. This is not to assume that other factors such as crosstalk or inter-system interference have become irrelevant, but in a situation where the effect of rain is so severe that a communication links no longer functions, then other factors can be considered as secondary. The effectiveness of wireless communication systems to a large extent depends on the transmission medium. Due to new needs and developments, system designers are interested in frequencies above 10 GHz. At these frequencies rain attenuation is one of the key parameters considered in link design and budgeting. For this reason, the International Telecommunication Union (ITU) recommends an expression for rain attenuation at a given frequency and rain rate [9]. Although this simple model (aR^b) is widely used in telecommunications [3], however, the model does not accurately account for rain induced attenuation everywhere in the world because the rain rate and drop size distribution changes and are different across the climatic regions of the world [7]. Consequently, a modification of the ITU-R model is important based on the actual climatic condition of a region for a reliable design of microwave link [6].

2. Objectives

The objectives of this study were to:

(i) Conduct performance analysis of the digital microwave links used in the A_{bis} Interface of GSM network under the effect of raindrops.

(ii) Determine the links worst faded signal level due to rainfall

(iii) Determine the rain induced attenuation from the measured Received Signal Level (RSL) variation on the links at 13GHz and 15GHz microwave links and develop empirical models for the accurate prediction of rain induced attenuation for microwave links based on the measured data

3. Methodology

The Received Signal Levels (RSL) of the microwave links in the Base Station Subsystem (BSS) of the GSM network interface (A_{bis} Interface), were taken during rainfall events and on clear sky, using a window based software (mini-link craft 2.13v) as the Transmission Evaluation and Monitoring System (TEMS). According to ITU-R [8], clear-sky is taken to be the condition of intrinsic atmospheric attenuation due to gases and water vapour without excess attenuation due to tropospheric precipitation such as rain and snow. The rain rate R_p data was extracted from the Nigerian Meteorological Agency NIMET data obtained for the two years period. Figure 3.1 showed the block diagram for the materials and method adopted.

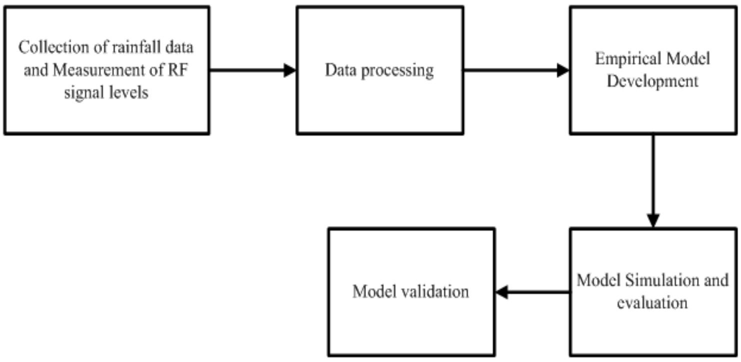

Figure 1: Block Diagram for Material and Method

The links performance analysis conducted based on the measured RSL and its variation between the clear sky signals and the faded signals due to rainfall showed a considerable drop to the extent of having service disruptions at some instant when the faded RSL drops below the link threshold values as shown in figure 2 and 3.

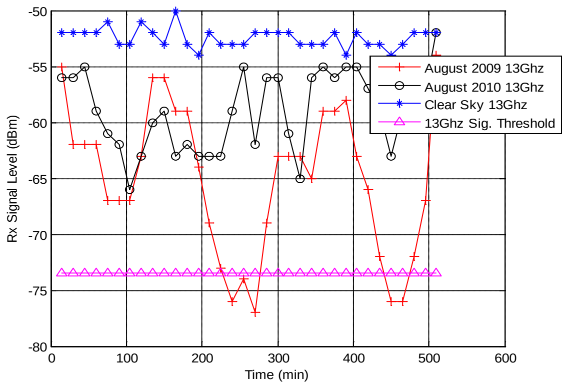

Figure 2: 13GHz Link RSL Variation

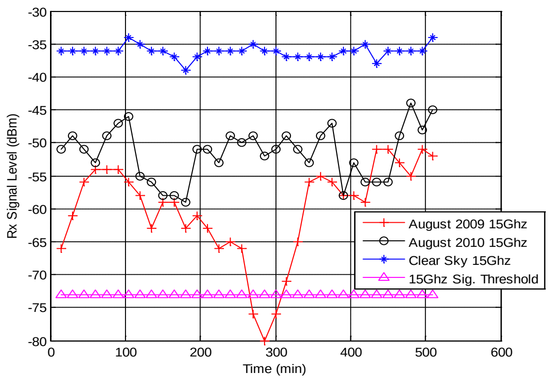

Figure 3: 15GHz Link RSL Variation

The link performance analysis showed clear cases of loss of service by the 13GHz link when the RSL crossed the threshold level of -73.5dBm. The RSL of the link dropped to the minimum of -77dBm. The 15GHz link service was disrupted by rainfall when the RSL of the link goes to about -80dBm against the threshold level of -73dBm. These are the established absolute fade margins of -77dBm and -80dBm for the 13GHz and 15GHz microwave links respectively during heavy rainfall. The difference between the faded received signal level due to raindrops and the clear sky (None faded) signal level captured from the links showed in Table 1 was used as the measured rain induced attenuation.

The measurement showed a high correlation with the rainfall rate extracted from the Nigeria Meteorological Agency (NIMET) as shown in Figure 4.

Table 1: Measured Rain Attenuation for 13 and 15GHz links

Months	13GHz Measured Attenuation (dB)			15GHz Measured Attenuation (dB)		
	2009	2010	Mean (A_p)	2009	2010	Mean (A_p)
April	2.08	3.35	2.72	3.11	3.93	3.52
May	2.62	5.55	4.09	4.55	7.75	6.15
June	6.28	11.28	8.78	12.95	17.88	15.42
July	2.68	6.35	4.52	6.28	14.95	10.62
August	12.95	6.82	9.89	19.95	15.08	17.52
September	8.75	8.75	8.75	7.95	16.68	12.32
October	6.02	5.62	5.82	11.95	10.55	11.25

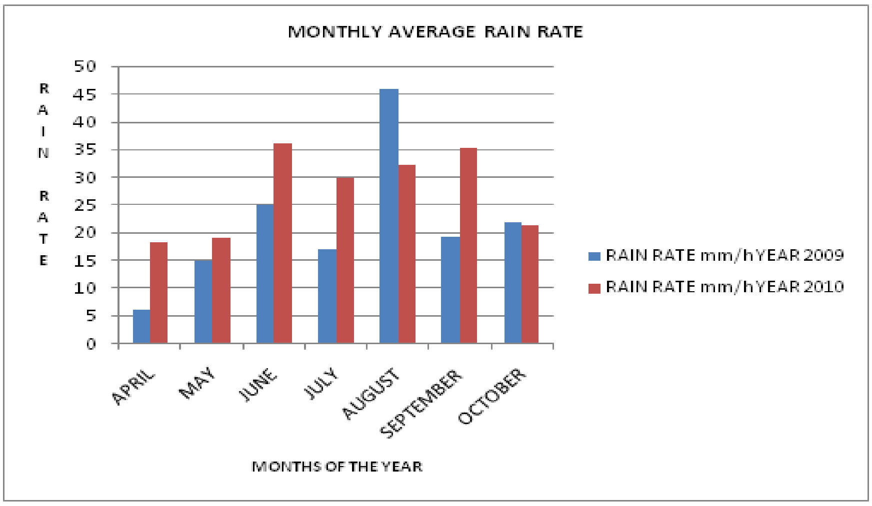

Figure 4: Monthly Average Rain Rate in 2009 and 2010 in Kaduna Nigeria

3.1 Model Development

The least squares method was used in the model development because it assumes that the best-fit curve of a given function is the curve that has the minimal sum of deviation squares for a given set of data. This was based on linear regression analysis. Linear model was used to examine the relationship between dependent and the independent variables. After performing an analysis on data, the regression statistics can be used to predict the dependent variable when the independent variable is known. This was normally being represented as:

Y = intercept + (slope, X) + error (1)

Where Y is the dependent variable and X is the independent variable

Even though the ITU-R power-law fits the non-linear least square relationship between the values of the independent and the corresponding conditional dependent mean values, the regression function was linear in the unknown parameters that are estimated from the data. For this reason the regression was considered iterative. Software solution like MATLAB or Microsoft Excel spreadsheet could be used for finding the best-fitting curves giving a set of points by minimizing the squared error. The Tread-line function of the Excel software is chosen for the modeling because it runs without additional codes and display of the curve-fitting coefficient of regression R^2.

Nonlinear regression problems can be moved to a linear domain by a suitable transformation of the model formulation.

Considering the ITU-R model [6]

$$A = aR^b$$
(2)

with parameters a and b. If we take the logarithm of both sides, this becomes

$$\ln(A) = \ln(a) + b\ln(R)$$
(3)

This has been clearly transformed to the linear regression equation (1)

The goal of the regression analysis was to model the expected value of a dependent variable y in terms of the value of an independent variable x. In simple linear regression, the model use was

$$y = a_0 + a_1 x + \varepsilon$$
(4)

Where ε is unobserved random error with mean zero condition on the independent variable x. In this model, for each unit increase in the value of x, the conditional expectation of y increases by a_1 units.

In general, we can model the expected value of y as an nth degree polynomial, yielding the general polynomial regression model for increased conditional expectation of y.

$$y = a_0 + a_1 x - a_2 x^2 + a_3 x^3 + \cdots + a_n x^n + \varepsilon$$
(5)

The mean rain rate (x) in Figure (4) is the independent variable and the mean measured attenuation (y) in Table

(1) is the dependent variable. The Excel Trend-line function chart was used to model for the best curve fitting functions as polynomial and power-law curve fittings, Figure 5 and Figure 6. The functions were further evaluated using statistical techniques.

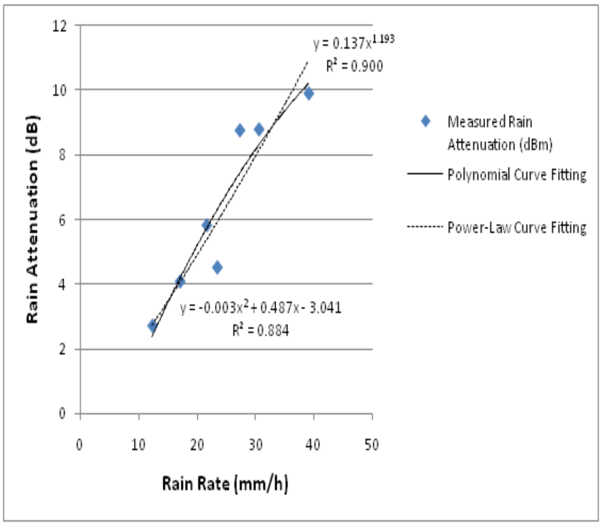

Figure 5: Predicted Models at 13GHz

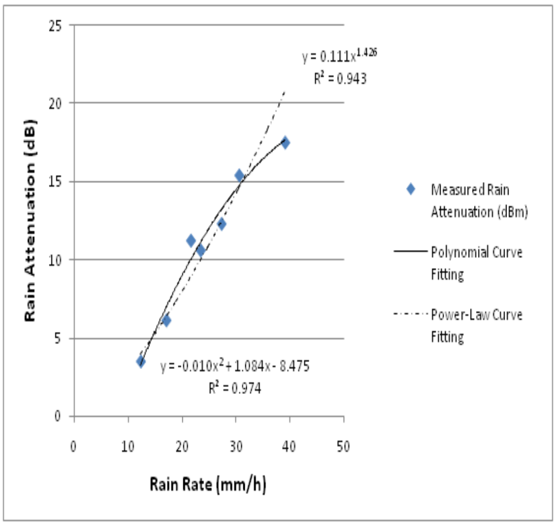

Figure 6: Predicted Models at 15GHz

3.2 Model Evaluation and Simulation

The predicted curve fitting functions were evaluated using the chi-square test and the root mean square error (RMSE) statistical techniques. The chi-square test is given by [7]:

$$x^2 = \sum_{i=1}^{N} \frac{(x_{mea,i} - x_{pre,j})^2}{x_{pre,j}} \quad (6)$$

at 5% degree of freedom. Where X_{mean} is the mean measured rain attenuation values of each link, X_{pred} is the predicted values from the analytical curves, N is the number of measured or predicted points ranging from 1,2...7 in this context. The hypothesis accepted all the curve fittings as good empirical models. The Root Mean Square Error (RMSE) evaluation given by [1]

$$\Delta_{rms} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left[\frac{100(A_{m,i} - A_{p,j})}{A_{m,j}}\right]^2} \quad (7)$$

showed the polynomial functions as the best curve fittings for both the 13GHz and 15GHz measured data. Where A_m is the mean attenuation, A_p is the predicted attenuation and N is the number of measured or predicted for i^{th} and j^{th} occurrence. The chosen polynomial fittings Table 2 were simulated using signal processing toolbox of MATLAB R2008a.

Table 2: Predicted Empirical Models

LINKS	Predicted Empirical Models
13GHz	A_p=-0.0038Rp^2+0.4878Rp-3.0414
15GHz	A_p= -0.0107Rp^2+1.0848Rp-8.4759

The simulation Figure 7, clearly demonstrated a linear relationship between the rainfall rate and the induced rain attenuation.

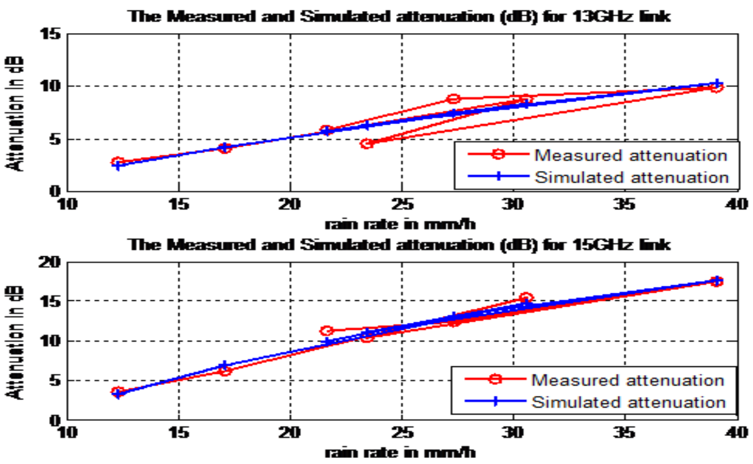

Figure 7: Simulation of the Developed Models

3.3 Comparison with ITU-R Model

The empirical models developed were compared with the ITU-R terrestrial attenuation model. The ITU-R model equation [4] expresses rain attenuation calculation to availability at (0.01%) percentage of time of the year. Consequently, the rain rate at 0.01% ($R_{0.01\%}$) was determined [5]. Figure 8 and Figure 9 showed the comparison of the two models.

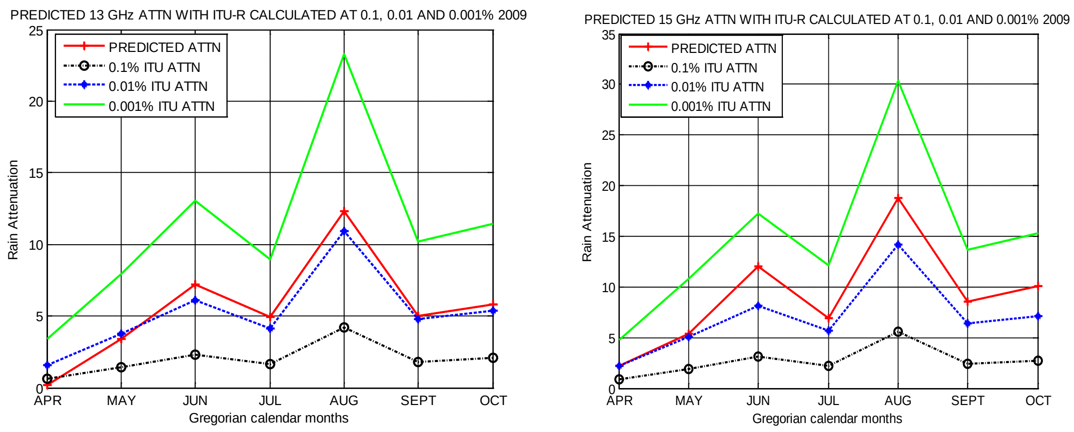

Figure 8: Comparism of predicted attenuation with ITU-R model in 2009

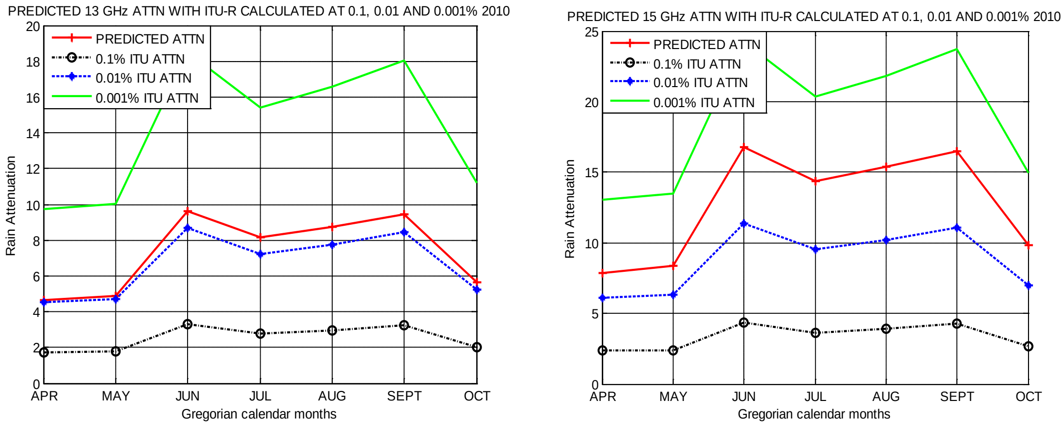

Figure 9: Comparism of predicted attenuation with ITU-R model in 2010

Generally, the ITU-R model predicted lower at both 0.1% and 0.01% time of the year. This means that the ITU-R model under estimated the rain-induced attenuation for the two microwave links in Kaduna-Nigeria.

4. Discussion and Conclusions

The attenuation measurement due to rainfall was obtained directly and it was also predicted using empirical modeling approach. Firstly, the links recorded unavailability of service at some instant of rainfall when the signal fade margin of -80dBm and -77dBm were recorded by the 15GHz and 13GHz link respectively. The chosen empirical models developed were the polynomial curve fitting functions because the two had the lowest root mean square error (RMSE) of 0.86 for the 13GHz and 0.73 for the 15GHz microwave link. The developed empirical model predicted excess rain attenuation of 11.35dB for the 13GHz and 18.78dB for the 15GHz microwave link while the ITU-R model gave 10.91dB excess attenuation values at the 13GHz and 14.21dB at 15GHz link as shown in Figure (8) and Figure (9). The ITU-R model under estimation of the excess attenuation values increased with frequency and rain rate. The comparison analysis showed that the predicted model had a mean error of 0.78dB and 3.02dB with respect to the ITU-R model. These excess values of attenuation due to rain had to be added to the links path loss as compensation in the link budget to make the links available throughout the year. The simulation results showed a mean model error (MME) of 0.00190 for the 13GHz with standard deviation (SD) of 0.0043 while the 15GHz showed a mean model error (MME) of 0.01079 with 0.0245 as its standard deviation (SD) value.

The predicted empirical models proved to give more precise rain induced attenuation results when compared with the ITU-R model at the 13GHz and 15GHz microwave frequencies. However, the models dependent variable is limited to the rainfall rate only. So, certain climatic considerations defined by the ITU-R parameter a and b in the model equation ($A_p = aR_p^b(d_{eff})$ were not specifically explained until the constants of the polynomial functions are further analysed.

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