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Performance Evaluation of Rain Attenuation Models in a Tropical Station

Yussuff Abayomi IO[1,2], Nor Hisham Bin Haji Khamis[1], Azli Yahya[1]
[1] Department of Communications Engineering, Universiti Teknologi Malaysia, Malaysia
[2] Department of Electronic and Computer Engineering, Lagos State University, Nigeria

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ABSTRACT

The non-uniformity of rainfall in both the horizontal and vertical directions makes the estimation of slant path attenuation complex. At frequencies above 10 GHz, the effects of attenuation and noise induced by rain are quite significant. One year satellite attenuation data were sourced from Malaysia East Asia Satellite at Ku frequency band; using ASTRO beacon signals to monitor and measure the slant path rain rate and attenuation at Universiti Teknologi Malaysia, Skudai. Four years' one minute rain rate ground data at 0.01% of time exceeded were collected using rain gauge. The attenuation exceeded for other percentages of the time was obtained using statistical methods. Different rain attenuation prediction models were investigated and their performances compared. The validation results clearly suggested that the Breakpoint attenuation prediction model produced better results when compared with other models of interest.

Corresponding Author:

Yussuff Abayomi IO,
Department of Communications Engineering,
Universiti Teknologi Malaysia, Malaysia.
Email: ayussuff@yahoo.com

1. INTRODUCTION

Rainfall in tropical regions is characterized by both stratiform and convective rainfall types, but more predominantly by the latter. Stratiform rainfall is characterized by widespread, low or medium rain rates with longer durations. Convective rain is usually confined to a smaller area than lighter rain, and the rain cells may take any shape. If rain rate is measured only at a single point, it is difficult to have adequate information about the structure of a rain cell at some distance away from the point of observation; hence, the in-homogenous nature of rainfall may lead to incorrect estimates of the specific attenuation.

There is also a dearth of data on direct attenuation measurement along the slant path for estimating attenuation due to rainfall in the tropical regions of the world. Most of the studies reported in the literature have been carried out in temperate regions where solid precipitation is prevalent [1], [2]. The distribution of rainfall along the slant path may lie within a single cell diameter if the elevation angle is very high. The higher the elevation angle, the lower the number of rain cells along the slant path. Rainfall with high rain rates of short durations and which are also contained within a small geographical area are features of convective rainfall types. Hansson's theory of the accumulation time factor (ACCF) [3] was used by [4] to estimate the effective rain height from the exceedance ratio at the breakpoints. The coincident pairs of points throughout the full range of attenuation and rain rate can be found from [3] and [5] by scaling the dB values to the ratio of rain rates referenced to the rainfall breakpoint. This is given by [6] as: -

$$A_B = \frac{A_{R\,0.01}}{R_{0.01}} * R_B \tag{1}$$

where A_B and $A_{R0.01}$ are attenuations (dB) at breakpoint and 0.01% of the time exceeded, respectively. Also, R_B and $R_{0.01}$ are rain rates (mm/h) at breakpoint and 0.01% of the time.

Universiti Teknologi Malaysia (UTM) is a tropical station (103.75°E, 1.45°N) with an altitude of 37 m above mean sea level; and with mean annual rainfall of 2357 mm. It experiences convective, stratiform, tropical storm and monsoon precipitations [2]. This work evaluates the performances of some of the most widely used rain attenuation models. These include the ITU-R, DAH, SAM, Mandeep, Crane and Breakpoint models.

1.1. An Overview of Rain Attenuation Prediction Models Used

International Telecommunication Union-Rec. P.618-11 rain attenuation model [7] is the most widely accepted international method for the prediction of rain effects on satellite communication systems. The predicted slant path attenuation exceeded for an average year at 0.01 % of the time is:

$$A_{0.01} = \gamma_{0.01} L_{eff} \quad dB \tag{2}$$

where $A_{0.01}$ and $\gamma_{0.01}$ are attenuation (dB) and specific attenuation (dB/km) at 0.01% of the time exceeded $Leff$ is the effective slant path length (km).

The predicted attenuation exceedances for other percentages of the time of an average year may be acquired from the value of $A_{0.01}$ using the following extrapolation [7]:

$$A_{P\%} = A_{0.01} \left(\frac{p}{0.01}\right)^{-[0.655+0.033\ln p - 0.045\ln A_{0.01} - z\sin\theta(1-p)]} dB \tag{3}$$

where p is the percentage probability of interest and z is given by:

$$For \quad p \geq 1.0\%,\ z = 0 \tag{4}$$

$$For \ \ p < 1.0\%,\ z = \begin{cases} 0;\ for\ /\phi/ \geq 36^0 \\ z = -0.005(/\phi/-36)\ \ for\ \theta \geq 25^0\, and\, /\phi/ < 36^0 \\ z = -0.005(/\phi - 36/) + 1.8 - 4.25\sin\theta,\ \ for\ \theta < 25^0\, and\, /\phi/ < 36^0 \end{cases} \tag{5}$$

DAH model [8] is based on log-normal distribution of rain rate and attenuation. The model is very much similar to the ITU-R model since the rain related input to the model is also rain intensity at 0.01 % of the time. It is applicable to both terrestrial and slant paths within the frequency range 4-35 GHz, and the percentage probability range of 0.001 – 10%. The behaviour of the localized DAH model can be modelled by the expression:

$$A_{P\%} = A_{0.01} \left(\frac{p}{0.01}\right)^{-[0.655+0.033\ln p - 0.045\ln A_{0.01}]} dB \tag{6}$$

where $A_{p\%}$ and $A_{0.01}$ are attenuation exceeded for $p\%$ and 0.01% of the time respectively.

Simple Attenuation Model (SAM) by [9] is one of the most widely used slant path attenuation prediction models, which incorporates the individual characteristics of the stratiform and convective types of rainfall. In convective rain storms, when R >10 mm/h [9], the effective rain height, H_R depends on the rain rate because strong storms push rain higher into the atmosphere, and thereby lengthening the slant path [10]. To determine the slant path attenuation, a modified value of effective path length is used, as follow:

$$A = \gamma_{0.01} \frac{1 - \exp\left[-\alpha\, b \ln\left(\frac{R_{\%p}}{10}\right)\right] L_S \cos\theta}{\alpha\, b \ln\left(\frac{R_{\%p}}{10}\right)\cos\theta};\ R_{\%p} > 10\,\text{mm/h}\ \ \text{dB} \tag{7}$$

where $b = 1/22$ and,

$$\gamma_{0.01} = k\, R_{\%p}^{\alpha} \quad dB\ /\ km \tag{8}$$

where k and α are ITU-R regression coefficients [11] whose values are dependent on frequency of operation, elevation angle of the antenna, polarization of the signal being transmitted or received, drop size distribution of rain drop and temperature of the antenna.

Mandeep's proposed model [10] adopted the SAM to calculate the effective path length. He proposed effective path length as a power-fitting function of rain rate as:

$$Leff = 13.367 * R_p^{-0.21} \quad km \tag{9}$$

Crane (Global) rain attenuation prediction model [12] is intended for rain attenuation predictions on either terrestrial or slant propagation paths. It was established with geophysical interpretations of the measurements of point rain rate of the horizontal structure of rainfall as well as the vertical variations of atmospheric temperature. Based on radar observations in the characterization of the melting layer, it was observed that the correspondence between the $0^{\circ}C$ isotherm height (H_0) values and the excessive precipitation events showed a tendency toward a linear relationship between R_p and H_0. Since, at high rain rates, the rain rate distribution function displays a nearly linear relationship between R_p and $\log P$, between 0.001% and 1.0 % of the form [12]:

$$H_0 = a + b\log P \quad km \tag{10}$$

where H_0 is mean $0^{\circ}C$ isotherm height above mean sea level and R_p is the rain rate for $p\%$ of the time exceeded.

$$H_0 = 4.5 + 0.0005\log R_p^{1.65} \quad km \tag{11}$$

where H_R is mean rain height above mean sea level.

The horizontal (surface) projected path length, D is expressed as:

$$D = \begin{cases} \dfrac{H_R - H_0}{\tan\theta}; \theta \ge 10^{\circ} \\ R_e \sin^{-1}\left[\dfrac{\cos\theta}{H_R + R_e}\left(\sqrt{(H_R+R_e)^2\sin\theta + 2R_e(H_R-H_0) + H_R{}^2 - H_0{}^2} - (H_0+R_e)\sin\theta\right)\right]; \theta < 10^{\circ} \end{cases} \tag{12}$$

where R_e is the effective radius of the earth [8500 km] and θ (degrees) is the elevation angle of the antenna to the satellite. However, for most tropical stations,

$$D = \frac{H_R - H_0}{\tan\theta} \quad km \tag{13}$$

The mean slant path attenuation at each probability of occurrence (*p*) is:

$$A_p = \begin{cases} \dfrac{kR_p{}^{\alpha}}{\cos\theta}\left[\dfrac{e^{U\alpha D}-1}{U\alpha}\right];\ 0 < D \le d \\ \dfrac{kR_p{}^{\alpha}}{\cos\theta}\left[\dfrac{e^{U\alpha d}-1}{U\alpha} - \dfrac{X^{\alpha}e^{Y\alpha d}}{Y\alpha} + \dfrac{X^{\alpha}e^{Y\alpha D}}{Y\alpha}\right];\ d < D \le 22.5 \end{cases} dB \tag{14}$$

$$X = 2.3R_p^{-0.17}; Y = 0.026 - 0.003\ln R_p; d = 3.8 - 0.6\ln R_p; U = \frac{\ln\left(Xe^{Yd}\right)}{d} \tag{15}$$

The Breakpoint model which is the ITU-R P.618-11 rain attenuation prediction model, was modified by [4]; and further modified by [13], is based on the premise that the ACCF at the breakpoints is invariant in the tropics. Also, for elevation angles less than 60° and with high rain rates, several rain cells were observed to intersect along the slant path [5]. The attenuation exceeded is projected by two expressions very much similar to the ITU-R model; with one expression for rain rates lower than the breakpoint rain rate (stratiform rainfall) while the other for rain rates above it represent the convective rainfall types, which is synonymous with tropical regions. The breakpoint attenuation exceedance, P_{AB}, and rain rate exceedance, P_{RB} is related as [13]:

$$P_{AB} = 2.14 \ P_{RB} \tag{16}$$

The approximate value of P_{AB} as 0.021% for measured and breakpoint attenuation exceedance for UTM, Malaysia at 12 GHz is shown in Figure 1.

The breakpoint (or modified Bryant) model is specifically developed for tropical regions. This is because of the peculiar nature of the rainfall precipitations existing in such regions. The model took into account both stratiform and convective rainfall types as experienced in the tropical and sub-tropical regions in its mathematical formulations to arrive at this model. It provided avenue for breakpoint analysis of attenuation exceedances and accounted for multiple (intersecting) rain cells along the slant path. The model has also been found to produce good results when applied for slant path attenuation predictions in tropical and equatorial stations [14].

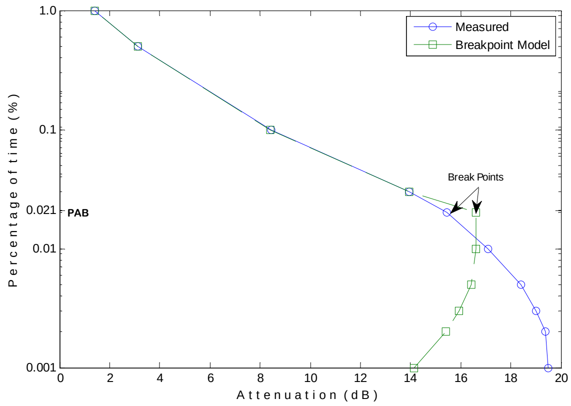

Figure 1. Measured and breakpoint attenuation exceedance for UTM, Malaysia at 12 GHz

The breakpoint attenuation (A_B) is computed from:

$$A_B = kR_B^{\alpha} * Leff \ * C_f \quad dB \tag{17}$$

where, correction factor

$$C_f = \begin{cases} -0.002|\theta|^2 + 0.175|\theta| - 2.3 \ ; \ 40° \le \theta < 60° \\ 1 \ ; \ \theta \ge 60° \end{cases} \tag{18}$$

where k and α are frequency dependent parameters which can be determined locally or obtained from ITU-R P.838-3 [11].

R_B is assumed to occur at $R_{0.01}$ due to paucity of long term rainfall database to work with in the tropical regions. Consequently, the corresponding attenuations at other percentages are computed as follows:

For stratiform rainfall,

$$A_p = A_B\left(\frac{p-0.011}{0.01}\right)^{-[0.655+0.033\ln(p-0.011)-0.045\ln A_B - z\sin\theta(0.989-p)]} dB \quad ; 0.021 \le p < 1 \tag{19}$$

For convective rainfall,

$$A_P = A_B\left(\frac{p}{0.021}\right)^{-[0.655+0.033\ln(p-0.011)-0.045\ln A_B - z\sin\theta(0.989-p)]} dB \;;\; p \le 0.021 \quad (20)$$

Equations (19) and (20) are modified versions of ITU-R P.618-11[7] of equation (3).

2. METHODOLOGY

2.1 Experimental Setup and Data Collection

One year (March 2001 to February 2002) satellite attenuation data was sourced from Malaysia East Asia Satellite (MEASAT). MEASAT offers direct to home (DTH) satellite broadcast services to South-Eastern regions of Asia at Ku frequency band. ASTRO beacon signal levels are used to monitor and measure the slant path rain rate and attenuation at location site (3.3^{o}N, 101.7^{o}E) at an altitude of 21.95 m above mean sea level. MEASAT 3 was positioned at 91.5^{o}E and at an elevation angle of 77.4^o. The beacon signal was received with an offset parabolic antenna dish of 2.4 m diameter. The vertically polarized Ku-band beacon signal was down-converted using a low-noise block converter (LNBC). The noise figure and bandwidth of the LNBC are 0.3 dB and 950 MHz respectively. The output of LNBC was passed through a 3 dB splitter and fed into a digital receiver and a spectrum analyzer with a post-detection bandwidth of 0 Hz. The spectrum analyzer was set to 10.982 GHz and the video filter output of the spectrum analyzer was recorded and stored in a computer at a sampling rate of 1.0 Hz, using a data logger. A Casella rain gauge was installed at the measurement site to record the rain rate. Shown in Figure 2 is the experimental setup for rain rate and beacon signal level.

One minute rain rate data were collected for a period of four years (January, 1997 to December, 2000) at UTM, Skudai, Malaysia using the Casella rain gauge. This tipping bucket rain gauge has a sensitivity is 0.5 mm/min; with operating temperature range of -10 to $50^{\circ}C$. It has a tipping accuracy of $\pm 100\ \%$. Scintillations are removed with a low-pass filter by passing low-frequency signals while attenuating signals with frequencies above the cut-off frequency.

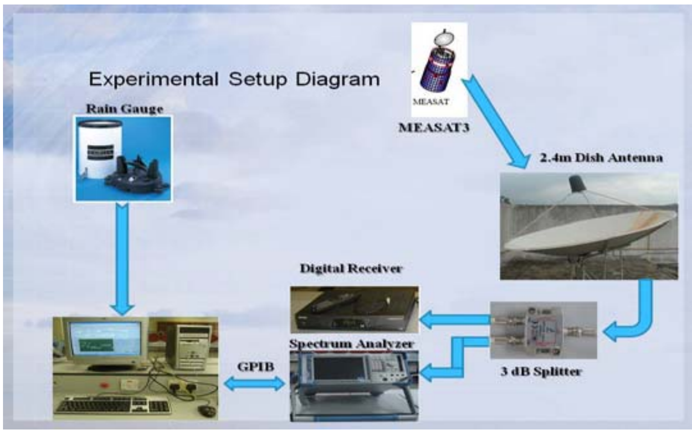

Figure 2. Experimental setup for rain rate and beacon signal level [15]

Thereafter, the corresponding path attenuation is calculated by finding the difference between the received signal level (RSL) during clear sky conditions and the RSL during rainy events for the vertically polarized received signal at various rain rates. That is,

$$Attenuation = RSL_{clear-sky} - RSL_{rainy} \quad \text{(dBm)} \quad (21)$$

The slant path attenuation exceedances for other percentages of the time for the average year were obtained using statistical interpolation and extrapolation methods.

3. RESULTS AND DISCUSSIONS

SAM prediction model performed poorly at all percentages of time (Figure 3). It largely over-estimated the measured data; and therefore not included in subsequent plots. There is good correlation between DAH and ITU-R models for 0.01% percentages of the time exceeded, since the rain intensity at 0.01 % of the time was the input for both models. The resulting plots of local rain data for all the models under investigation (excluding SAM) shows that higher percentages of unavailability translates to higher rainfall attenuations as seen in Figures 4 and 5.

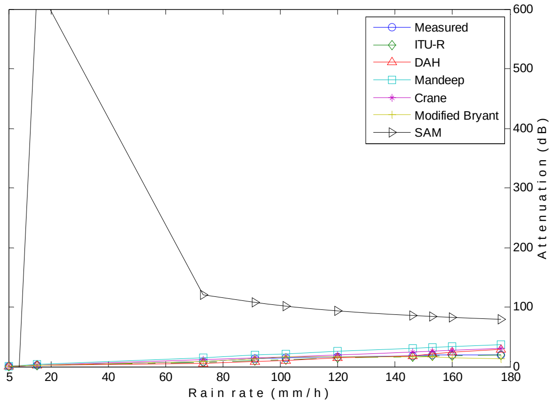

Figure 3. Equal probability plots of slant path attenuation at 12 GHz for UTM with SAM

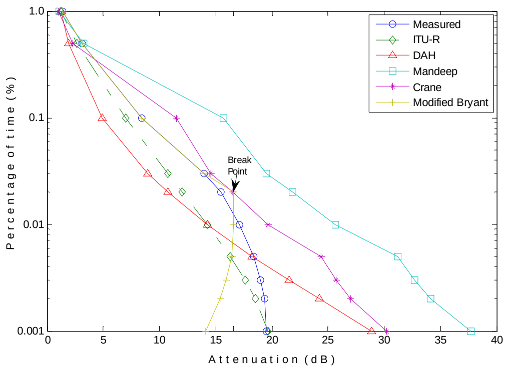

Figure 4. Slant path attenuation versus percentage of time exceeded at 12 GHz for UTM, Malaysia

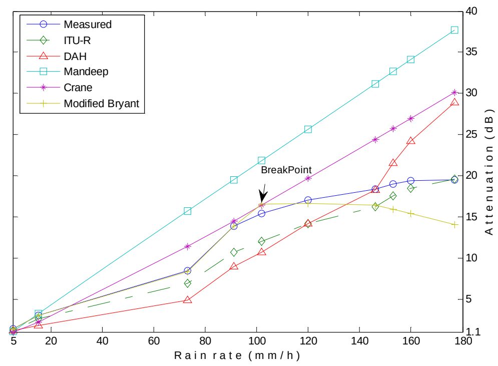

Figure 5. As in Figure 3, but without SAM

Next, Mandeep's proposed model over-estimated the measurements for most of time (at $p > 0.5\%$). Equally, Crane model over-estimated the measurement data all through (except at $p = 0.5\%$, $p = 1.0\%$, and $p = 0.03\%$). In the same manner, the modified Bryant (Breakpoint) model matches the measurements best for stratiform rain events (below the breakpoint at $p \leq 0.021$), as shown in Figure 4. Furthermore, the Breakpoint model began to slightly deviate from the measured values at $p \leq 0.03\%$. The ITU-R model, on the other hand, significantly under-estimated the measured data at $0.002 \leq p \leq 0.5\%$, except for 0.001% of the time. This under-estimation of the measurement beyond 102 mm/h is an indication of the ITU-R model unsuitability for attenuation prediction for tropical regions, which are identified with prevalent convective rainfall precipitations.

Shown in Table 1 are the percentage mean, RMS and standard deviation errors for the respective prediction models of interest at various percentage of time exceeded. The modified Bryant model estimate was observed to be closely correlated with the measurement data for stratiform rain events, which is defined by attenuation values below the breakpoint. The ITU-R model prediction mostly under-estimated the measurement for most percentages of the time, except for 0.001 % of the time.

According to the evaluation procedures adopted for comparison of prediction methods by the Recommendations ITU-R P.311-13 [16], the best prediction method produces the smallest values of the statistical parameters. Therefore, the modified Bryant model was observed to produce the best prediction compared to other prediction models of interest since it has the lowest root mean square (RMS) values, for majority of the time percentages.

4. CONCLUSIONS

The modified Bryant model produced the best prediction performance, followed by the ITU-R model in comparison to other prediction models of interest. This is because the modified Bryant model took into account both stratiform and convective rainfall types as experienced in the tropical and sub-tropical regions in its formulations. Furthermore, the use semi-empirical approach (as done in this work) saves cost and time. More importantly, the prediction model can quite easily be extrapolated to other sites with relatively good degree of accuracy; thus, making it possible to estimate the slant path attenuation exceeded for any location and for all percentages of time.

Table 1. Mean error, standard deviation and RMS values for different percentage of time exceeded

Parameter	**Prediction Models**	**Time percentage (% P)**									
		0.001	**0.002**	**0.003**	**0.005**	**0.01**	**0.02**	**0.03**	**0.1**	**0.5**	**1.0**
Mean	ITU-R	0.0008	-0.0045	-0.0073	-0.0116	-0.0168	-0.0222	-0.0231	-0.0173	-0.0149	-0.0147
Error	DAH	0.0482	0.025	0.0133	-0.0008	-0.0168	-0.0306	-0.0357	-0.0416	-0.0387	-0.0147
	SAM	0.3083	0.3279	0.3447	0.3678	0.449	0.5551	0.6682	1.3233	20.3851	-8.0366
	Mandeep	0.0936	0.0762	0.072	0.0693	0.0502	0.0414	0.04	0.0327	0.005	-0.022
	Crane	0.0548	0.0393	0.0353	0.0325	0.0151	0.0066	0.0043	0.0355	-0.0257	-0.0294
	BreakPt.	-0.0276	-0.0206	-0.0161	-0.0108	-0.0028	0.0074	0	-0.0004	0	0
	ITU-R	0.1502	0.1501	0.15	0.1497	0.1492	0.1485	0.1484	0.1492	0.1494	0.1495
Std.	DAH	0.297	0.2999	0.3006	0.3009	0.3004	0.2994	0.2988	0.298	0.2984	0.3006
Dev.	SAM	109.761	109.761	109.761	109.761	109.76	109.76	109.759	109.753	107.852	106.12
	Mandeep	0.5575	0.5601	0.5607	0.561	0.563	0.5638	0.5639	0.5643	0.5652	0.5648
	Crane	0.3104	0.3127	0.3132	0.3135	0.3148	0.3151	0.3152	0.3132	0.3141	0.3138
	BreakPt.	0.1243	0.1256	0.1263	0.1268	0.1273	0.1271	0.1273	0.1273	0.1273	0.1273
	ITU-R	0.1502	0.15	0.1498	0.1493	0.1483	0.1469	0.1466	0.1482	0.1487	0.1487
RMS	DAH	0.2931	0.2988	0.3003	0.3009	0.3	0.2978	0.2967	0.2951	0.2959	0.3002
	SAM	109.76	109.76	109.76	109.76	109.759	109.758	109.757	109.745	105.9082	102.35
	Mandeep	0.5496	0.5549	0.556	0.5567	0.5608	0.5622	0.5624	0.5634	0.5652	0.5644
	Crane	0.3055	0.3102	0.3112	0.3118	0.3145	0.3151	0.3151	0.3112	0.3131	0.3124
	BreakPt.	0.1212	0.1239	0.1253	0.1264	0.1273	0.1269	0.1273	0.1273	0.1273	0.1273

REFERENCES

[1] GO Ajayi and EBC Ofoche. "Some Tropical Rainfall Rate Characteristics at Ile-Ife for Microwave and Millimeter Wave Application". *Journal of Climate and Applied Meteorology*. 1984; 23: 562-567.

[2] AI Yussuff and NH Khamis. "Rain Attenuation Modelling and Mitigation in the Tropics: Brief Review". *International Journal of Electrical and Computer Engineering*. 2012; 2(6): 748-757.

[3] L Hansson. "New concept Used to Predict Slant path Rain Attenuation Statistics". *Microwaves, Antennas and Propagation, IEE Proceedings H*. 1990; 137(2): 89-93.

[4] QW Pan and GH Bryant. "Effective rain-cell diameters and rain-column heights in the tropics". *Electronics Letters*. 1994; 30(21): 1800-1802.

[5] F Moupfouma. "More About Rainfall Rates and their Prediction for Radio Systems Engineering". *Microwaves, Antennas and Propagation, IEE Proceedings H*. 1987; 134(6): 527-537.

[6] GH Bryant *et al.* "Rain Attenuation Statistics from Rain Cell Diameters and Heights". *International Journal of Satellite Communications*. 2001; 19(3): 263-283.

[7] ITU-R P.618-11. "Propagation data and prediction methods required for the design of Earth-space telecommunication Systems". *Recommendation, ITU-R Radio Propagation Series*: International Telecommunications Union, Geneva, 2013.

[8] A Dissanayake *et al.* "A Prediction Model that Combines Rain Attenuation and Other Propagation Impairments along Earth-Satellite Paths". *IEEE Transaction on Antennas and Propagation*. 1997; 45(10): 1549-1558.

[9] WL Stutzman and KM Yon. "A Simple Rain Attenuation Model for earth-space radio links operating at 10-35 GHz". *Radio Sciences*. 1986; 21(1): 65-72.

[10] JS Mandeep *et al.* "The Study of Rain Specific Attenuation for the Prediction of Satellite Propagation in Malaysia". *Journal for Infrared Milli Terahz Waves*. 2010; 31: 681-689.
[11] ITU-R P.838-3. "Specific Attenuation Model for Rain for use in Prediction Methods". *Recommendation, ITU-R Radio Propagation Series*: International Telecommunications Union, Geneva, 2003.
[12] RK Crane. "Prediction of Attenuation by Rain". *Communications, IEEE Transactions*. 1980; 28(9): 1717-1733.
[13] V Ramachandran and V Kumar. "Modified rain attenuation model for tropical regions for Ku-Band signal". *International Journal of Satellite Communications and Networking*. 2007; 25(1): 53-67.
[14] AY Abdulrahman *et al.* "An Improved Slant Path Attenuation Prediction Method in Tropical Climates". *Radioengineering*. 2013; 22(4): 1082-1090.
[15] AY Abdulrahman. "Development of Terrestrial rain Attenuation Transformation Model for Slant-Path attenuation predictions in Tropical Regions". PhD Thesis: Universiti Teknologi Malaysia. 2012.
[16] ITU-R P.311-13. "Acquisition, presentation and analysis of data in studies of tropospheric propagation". *Recommendation, ITU-R Radio Propagation Series*: International Telecommunications Union, Geneva. 2009.

BIOGRAPHIES OF AUTHORS

Abayomi Isiaka O Yussuff obtained his bachelor and master's degrees in Electronic and Computer Engineering from Lagos State University, Nigeria in 1994 and 2003; and a PhD in Electrical Engineering from Universiti Teknologi Malaysia (UTM), Skudai, Malaysia in 2014. He is currently a researcher and lecturer in the Department of Electronic and Computer Engineering, Lagos State University, Epe campus, Nigeria. His research area of interests includes radio propagation and rain attenuation studies in the tropics, computer security, electronic instrumentation and measurements. He has published a few papers in international journals related to satellite rain attenuation issues in the tropical regions. He is a member of Nigeria Society of Engineers (NSE) and IEEE; and licensed by the Council for Regulation of Engineering in Nigeria (COREN).

Nor Hisham Haji Khamis is a senior lecturer in the Department Communications Engineering, Faculty of Electrical Engineering Department, Universiti Teknologi Malaysia, Skudai, Johor. He received his B.Sc.E.E. from the University of Evansville, Indiana, USA in 1988, M.E.Sc.E.E. from the University of New South Wales, Australia in 1992, and PhD from UTM in 2005. He joined UTM in 1989 and currently is the Head of Radar Laboratory. He is also the subject coordinator for the Microwave Engineering, RF Microwave Circuit Design, and Radar courses at the faculty. He also leads the Sonar and Marine Instrumentation Research Group (STAR). His research interest includes antenna design especially microstrip antenna, microwave components, wireless transmission, and propagation studies. Dr. Khamis is a member of Eta Kappa Nu (Electrical Engineering Honor Society, USA) and IEEE.

Azli Yahya is a senior lecturer in Universiti Teknologi Malaysia since 1998 until now. He holds a degree in Electro Mechanical Power System and Master's Degree in Electronic Production from Glamorgan University, UK. He is a doctorate of Loughborough University, UK specializing in Electronic and Electrical Engineering. His areas of researches are Analog/Digital Circuit Design, Electrical Discharge Machining and Power Supply Design.