IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 13, Issue 3, Ver. II (May. - June. 2018), PP 60-64
www.iosrjournals.org

Analysis of Cloud Attenuation Effect on Satellite Communication Systems in Southern Nigeria

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Abstract: *This paper analyses the cloud attenuation effects of communication signals at frequencies of 20-50GHz in the southern region of Nigeria. The methodology adopts the modified model for specific attenuation due to cloud postulated by Lorenzo and Capsoni. The values of specific attenuation under the given conditions of cloud cover were computed by using the absorption coefficient of cloud liquid water* $\mathbf{a_w}$*and not the traditional use of directly compute cloud liquid water content* **w**. *The chosen locations are Port-Harcourt, Benin and Uyo.*

Date of Submission: 07-06-2018 Date of acceptance: 26-06-2018

I. Introduction

Satellite Communication system is usually characterized with faded signals and delays in signal processing due to adverse weather condition as a result of atmospheric gases, fog, cloud, tropospheric scintillation and so on[1].The problem becomes more acute at frequencies above 10GHz for Ku and Ka frequency band. The effect is always more pronounced in the tropical region associated with high relative humidity, cloud formation and high rain intensities[2].

Cloud impairment increases the rate of attenuation of signals in the satellite communication links thereby resulting to poor services. Majority of these cloud impairments are due to rainfalls, high relative humidity and other unfavorable climatic conditions. It is therefore necessary to have good predictions of these impairments which will subsequently help in the design, location and deployment of satellite system especially in tropical regions around the world (Nigeria as a case study).

Cloud attenuation is primarily due to absorption by the cloud droplets; scattering losses were secondary. For clouds at an altitude above the zero degree isotherms, absorption by ice particle is negligible because the imaginary component of the index of refraction of ice is very small. Tropical regions such as the southern part of Nigeria are not known to exhibit ice cloud formation.

In order to understand the concept of absorption by cloud droplets, the liquid water content of the cloud formation must equally be ascertained. The liquid water content varies in a very broad span.The large Cumulonimbus and Cumulus Congestus that accompany thunderstorms have especially high values of liquid water content; fair weather Cumulus clouds generally have liquid water content of less than 1 g/m3. Stratiform or layered clouds display ranges of 0.05 to 0.25 g/m3. Stratocumulus is the densest of this cloud type (0.3 to 1.3 g/m3). Sometimes, the values of M exceed 5 g/m3 in Cumulus Congestus; an average value of 2 g/m3 for Cumulus Congestus and 2.5 g/m3 for Cumulonimbus clouds are reported[3&4].

Thus, this work will progress by exploring detailed information on impairment of electromagnetic signals by cloud bodies in Nigeria and will on that premise develop a wholesome model with respect to these study locations; Uyo, Benin city and Port-Harcourt. This paper will apply a cloud attenuation model centered on the mass absorption and integrated liquid water variable. The results and conclusion of this work will be subsequently disclosed.

II. Cloud Attenuation Calculation

An approach to estimate cloud attenuation which involves the direct use of the mass absorption coefficient for liquid water, $a_W(f)$ is used in this paper[5]. It has been widely employed in remote sensing applications to relate the integrated liquid water content W to the associated cloud attenuation $A_W$at a given frequency f, the mathematical representation is shown thus:

$$A = aw(f).W \qquad [dB] \qquad (1)$$

The integrated liquid water content W, is gotten from Radiosonde data in conjunction with the Salonen model for computing Liquid water content[7]:

$$LWC = W_o \rho_w (1 + cT) \left(\frac{H_c}{H_r}\right)^a$$

$$where: a = 1.4; c = \frac{0.041}{°C}; Wo = \frac{0.14gm}{m^3} for\ each\ radiosconde\ ascent$$

The Liquid water content of this model is a function of the temperature profile of the atmosphere. That is for any temperature greater than 0^oC, the Liquid Water Content is significant. The Liquid Water Content (LWC) is also a function of temperature (T^oC) and height (Hc) from the base

It is discovered that the differences in a_W that were found when repeating the researchof computing the relationship between cloud attenuation (A) and the integrated water content W for 14 different stations across Europe were negligible for the radio-wave propagation applications addressed in the work for which it was first proposed[13]. This indicates that, notwithstanding the difference both in the type and in the occurrence of clouds among the various sites, their vertical development, in terms of relationship between pressure, temperature and relative humidity, is similar. As a result, the following expression can be used to estimate a_W as a function of frequency (*f*):

$$aw = \frac{af^b + cf^d + e}{f} \times K \qquad (2)$$

Where: a = 0.0155, b = 1.668, c = 14.8523, d = 0.3885 and e = -27.4863, 20 GHz ≤ *f* ≤ 200 GHz

K =specific attenuation by water droplets

$$K = 0.819f/\varepsilon''[1 + (\eta)^2] \qquad (3)$$

$$\eta = (2 + \varepsilon')/\varepsilon'' \qquad (4)$$

$$\varepsilon' = \varepsilon_2 + \frac{(\varepsilon_o - \varepsilon_1)}{1 + (\frac{f}{fD})^2} + \frac{(\varepsilon_1 - \varepsilon_2)}{1 + (\frac{f}{fs})^2} \qquad (5)$$

$$\varepsilon'' = \frac{f(\varepsilon_o - \varepsilon_1)}{fD\left[1 + \left(\frac{f}{fD}\right)^2\right]} + \frac{f(\varepsilon_1 - \varepsilon_2)}{fs\left[1 + \left(\frac{f}{fs}\right)^2\right]} \qquad (6)$$

$$\varepsilon_o = 77.67 + 103.3\left(\frac{300}{T} - 1\right) \qquad (7)$$

$$F_D = 20.09 - 142(\emptyset - 1) + 294(\emptyset - 1)^2 \qquad (8)$$

$$F_s = 590 - 1500(\emptyset - 1) \qquad (9)$$

$$\emptyset = \frac{300}{T}$$

$$\varepsilon_1 \& \varepsilon_2 = 5.48 \& 3.41$$

Where; ε' & ε" = the real and imaginary parts of the dielectric permittivity of water, ε.

T = temperature expressed in Kelvin.

ϕ = the inverse temperature parameter with T in Kelvin

F_D& Fs= the principal and secondary relaxation frequencies

f = frequency of signal

III. Data

The model formulation approach considers the occurrence of liquid cloud water in our study locations since it bests support the cloud type and climatic behavior of each study location. We will investigate the total columnar content of liquid water and the surface temperature for our three study locations by plotting gradients from the AIRS data presented[2&14].

Table 1: Table containing cloud data for chosen south-south locations in Nigeria.

TOTAL COLUMNAR LIQUID WATER CONTENT based on % unavailability of an average year.																
STATE CAPITALS	AVERAGE SURFACE TEMPERATURE T (K)	AVERAGE SURFACE PRESSURE P (hpa)	LATITUDE OF EACH STATION	LONGITUDE OF EACH STATION	0.01%	0.10%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
Benin	300.2	997.6	6.22	5.39	2.6	2.4	2.3	2.1	2.1	2	1.9	1.8	1.7	1.5	1.5	1.5
Port harcourt	299.6	987.1	4.43	7.02	2.8	2.5	2.4	2.3	2.2	2.1	2	1.9	1.8	1.7	1.7	1.6
Uyo	300.4	991.6	5	7.57	2.7	2.5	2.4	2.3	2.2	2.1	2.1	2	1.9	1.8	1.8	1.7

IV. Result

To establish the formulated model, we will develop Matlab scripts for computing the equations proposed above. The following tables and graphs were extracted through Microsoft excel and serve as the results of the computations undergone.

Table 2: Results for the location of Port-Harcourt

ABSORPTION COEFFICENT (dB/mm)	SPECIFIC ATTENUATION(dB/Km)	FREQUENCY (GHZ)
0.2069	0.185	20
0.7571	0.7201	40
1.5442	1.5514	60
2.5135	2.6057	80
3.6165	3.8072	100

Table 3: Results for the location of Benin

ABSORPTION COEFFICENT (dB/mm)	SPECIFIC ATTENUATION (dB/km)	FREQUENCY(GHZ)
0.2049	0.1832	20
0.7502	0.7587	40
1.5313	1.5384	60
2.4948	2.5863	80
3.5933	3.7828	100

Table 4: Results for the location of Uyo

ABSORPTION COEFFICENT (dB/mm)	SPECIFIC ATTENUATION (dB/km)	FREQUENCY(GHZ)
0.2041	0.1825	20
0.7475	0.7109	40
1.5262	1.5333	60
2.4874	2.5787	80
3.5841	3.7731	100

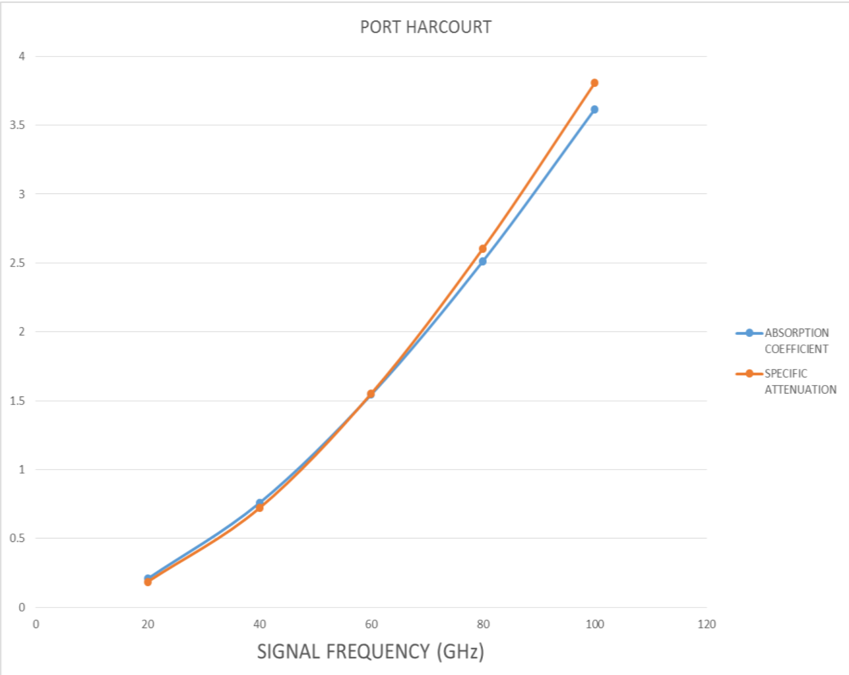

Figure 1: Graph plot of specific attenuation and absorption coefficient against frequency for the location of Port-Harcourt

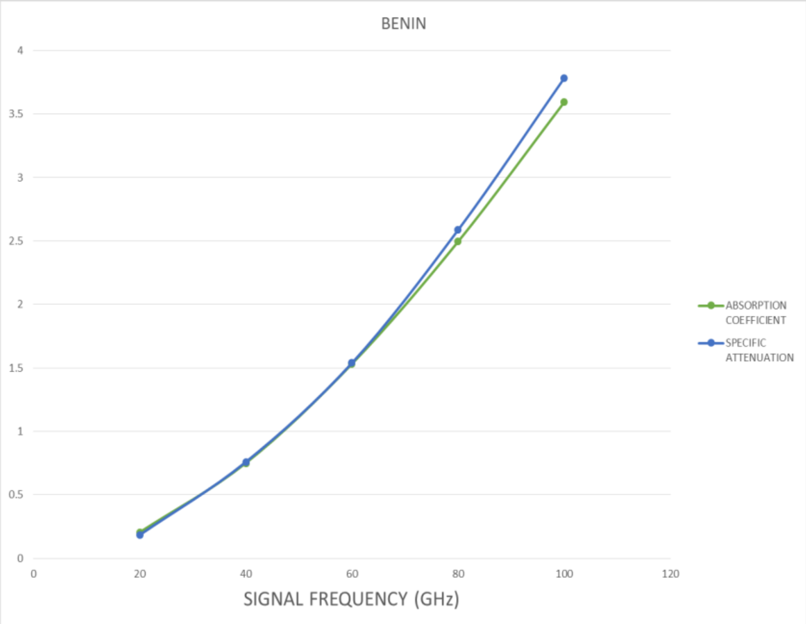

Figure 2:Graph plot of specific attenuation and absorption coefficient against frequency for the location of Benin

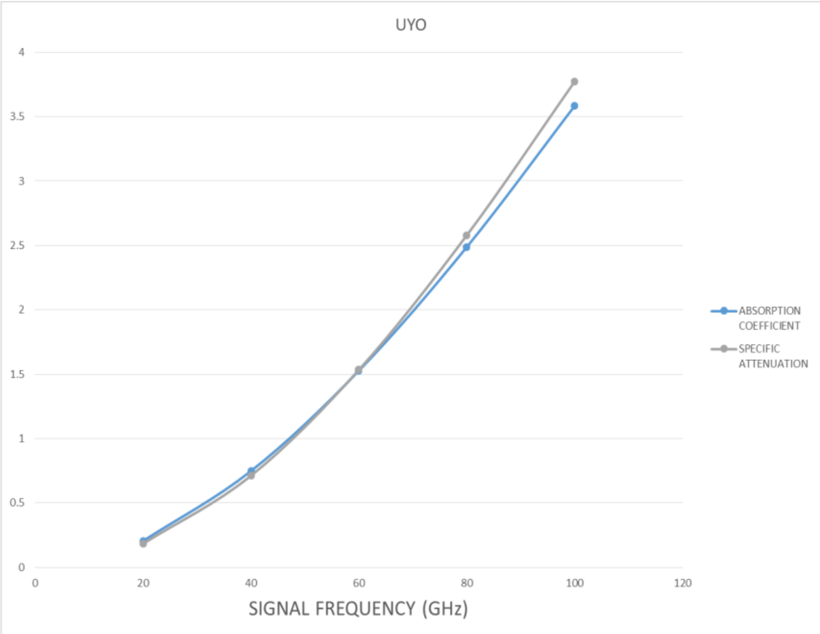

Figure 3: Graph plot of specific attenuation and absorption coefficient against frequency for the location of Uyo

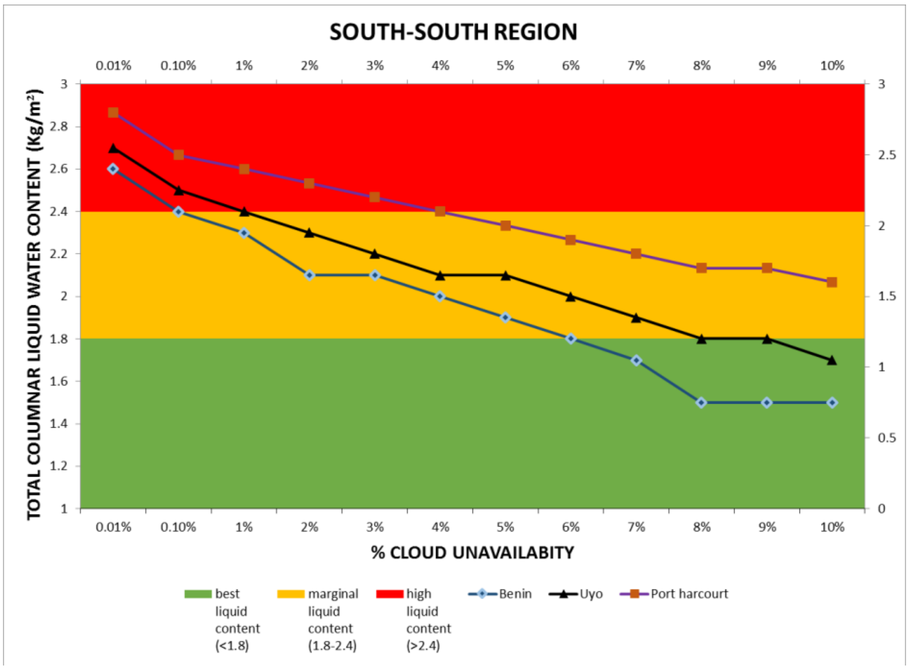

Figure 4: Liquid water content of the three locations against % cloud unavailability

V. Conclusion

A simple and accurate approach to calculate cloud attenuation A for Earth-space communication systems operating in frequency ranges above 10GHz is presented and assessed here. The model is the result of an analysis data collected in three locations in the Southern region of Nigeria. The model is based on a simple analytical expression for the mass absorption coefficient of liquid water a_W that is function of frequency and is independent of the site of interest. The knowledge of a_W and of the integrated liquid water content W is thus sufficient to calculate cloud attenuation in any site subject to temperate or tropicalclimate.

Computation of the model based on the data from the chosen locations also shows a marked similarity in the absorption coefficient behavior of the different locations. This further buttresses the fact that absorption coefficient is independent of site/location atmospheric data and this model will be suitable for analysis in other locations with a different climate to the study locations.

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