IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 13, Issue 3, Ver.III (May. - June. 2018), PP 12-16
www.iosrjournals.org

Effective calculation of Cloud Attenuation on Satellite Communication Systems in Nigeria based on Cloud Type

Ehikhamenle M.[1], Edeko F. O.[2]
[1](*Electrical and Electronic Engineering Department, University of Port Harcourt, Nigeria*)
[2](*Electrical and Electronic Engineering Department, University of Benin, Nigeria*)
Corresponding Author: Ehikhamenle M

Abstract: *This project aims at analyzing the attenuation due to clouds at 20-50GHz; to generate an accurate prediction model of cloud attenuation efficient for slant-path links and also evaluate the impact of cloud attenuationdynamics on these frequencies in the selected location of southern Nigeria. The methodology adopts ITU-R 840.4 model for specific attenuation due to cloud and average properties of four distinct cloud types. The values of specific attenuation under conditions of cloud cover were computed by using the obtained liquid water content values at frequencies starting from 20 GHz and up to 50 GHz.*

Date of Submission: 10-06-2018 Date of acceptance: 30-06-2018

I. Introduction

The telecommunication market today is driven into frenzy by the increasing demands of the end users for increased multimedia services, which on the long run demand high data rates. A common experience is therefore that as the demand for bandwidth increases, lower frequency ranges become more congested (as low frequency telecommunication consumer activities increase rapidly) and thus designers (of satellite infrastructures and satellite networks) are forced to employ higher frequency bands and regions which are majorly:-The C (4 to 8 GHz), Ku (12 to 18GHz), Ka (26.5 to 40 GHz) and V (40 to 75GHz) bands.

In Satellite communication, raindrops and cloud particles have become one of the biggest attenuating factors of the electromagnetic waves propagated in the atmosphere, especially at frequencies of 10 GHz and higher. Impairments, such as rain attenuation and cloud attenuation, become increasingly noticeable as well as problematic with increasing operating frequency. Although the effect of rain on electromagnetic propagation seems greater than that of clouds in many cases, the occurrence of clouds is always more often than rains. Though extremely detrimental, the presence of rain along a typical Earth-space link is limited to approximately 5%–10% of the time in a year, on the other hand, clouds cause a more limited impairment on the system, but are characterized by a much higher probability of occurrence (40%–80% yearly)[2].

Cloud attenuation can be attributed to both the density and amount of suspended liquid water droplets within the cloud at microwave and millimeter frequencies[1]. It is therefore vital to investigate the effects of clouds on electromagnetic signals in order to devise models to predict cloud attenuation probabilities and effects, especially when very high frequencies are considered, and/or when low elevation links are involved[2].

Although several models have been postulated for the prediction of cloud attenuation, an evaluation of these models has revealed them to be either poor estimators or too cumbersome as the input data required are difficult to obtain for a general purpose application[3].

In view of this, a cloud attenuation model generated from the available cloud cover data and the average properties of different cloud types would be discussed. This data will be gotten from information extracted from a cloud cover atlas based on a 10 year observation period of cloud types[4]. Four cloud types are selected for the postulation of the cloud attenuation model: cumulus, cumulonimbus, stratus, and nimbostratus. Average properties of these clouds and their occurrence probabilities are used in characterizing the cloud attenuation.

II. Cloud Classification

In this paper, three different classifications are of great import. The most extensively discussed are classifications based on cloud form, and cloud height as is seen in the works of Ahmed Ali Rais Kokab[5]. However, the location of choice is a tropical region and therefore, the classification by cloud composition will be as important as the other two classifications.

- **Cloud Composition**

Clouds composition is of either water droplets or ice crystals. **Ice clouds**, by virtue of the low dielectric constant of ice and the small size of the constituent particles, are not expected to cause appreciable attenuation to radio-waves in the frequency range below about 50 GHz[3]. **Water clouds** on the other hand are more problematic as the water droplets either absorb or scatter the electromagnetic signal leading to a marked attenuation of signal power. However, the attenuation is dependent on the liquid water content of the cloud and this varies based on height and form. The water cloud and its variable liquid water content forms part of the requirements of our prediction model.

- **Cloud Form**

Cloud classification by cloud form basically falls under 4 prefixes: the Ciriform, Stratiform, Cumuliform and Nimboform. The **Ciriform** clouds are thin, wispy clouds. They are composed mostly of ice crystals. And they are found very high in the atmosphere. The **Stratiform** clouds are layered, flat and spread out like “sheets”. This type of cloud seems to have no individual clouds lumps even with a few breaks in the layers. They are associated with stable atmospheres and climates. The **Cumuliform** clouds are formed in heaps. They are puffy, and develop vertically in individual cloud units although they generally seem to have flat bottoms like the stratiform clouds. They are associated with unstable atmospheres. The **Nimboform** clouds are thick, lumpy clouds composed of rain and precipitation. They are formed during rainy weathers and thunderstorms and low-height clouds.

- **Cloud Height**

In this classification there are three main classes: the High-level, Mid-level and Low-level clouds.
The **High-level** clouds exist at heights above 20,000 feet[6](above 6km). At this height the cloud formation is mostly cirriform with just two slight deviations making the Cirrus cloud, the Cirristratus cloud and the Cirricumulus cloud. These clouds are by nature very thin and greatly spaced (except for the cirristratus which is a very thin cloud layer) and are composed of mostly ice crystals. This makes this class irrelevant to the work, since at the height and composition of such clouds attenuation is very minimal until frequencies of 50GHz and above.
Mid-level clouds are formed at heights ranging above 6,500 and below 20,000 feet (1.98 to 6 kilometers). These clouds may be composed of liquid water droplets, ice crystals, or a combination of the two depending on factors such as the altitude, season, and vertical temperature structure of the troposphere. The two main types of mid-level clouds are the altostratus and altocumulus. They also vary between either becoming flat, sheet-like and layered with individual cloud formations (such as the altostratus) or they become lumpy, thick and form individually (such as altocumulus). This class of cloud however contains more ice than water for most of the year.
Low-level clouds are found within 6,500 feet and below. They normally consist mostly of liquid water or even super-cooled water droplets, except during cold winter storms when ice crystals (and snow) comprise much of the clouds. The two main types of low clouds include **stratus**, which develop horizontally, and **cumulus**, which develop vertically. However, between the stratus and cumulus which are: stratus-cumulus, nimbus-stratus, cumulus-nimbus. The cloud forms with the nimbus composition have the highest level of water content as they are formed during thunderstorms.
Table 1 below shows the average properties of the four cloud types used in attenuation model. This includes the cloud height and length as well as their liquid water content.

Table no 1: Shows metabolic parameters of patients of the three groups before treatment.

Cloud type	Water content (g/m3)
Cumulonimbus	1.0
Cumulus	0.6
Nimbostratus	1.0
Stratus	0.4

III. Calculation of Cloud attenuation

Cloud liquid water is a measure of the total liquid water contained in a cloud in a vertical column of atmosphere. This parameter does not engulf solid water and thus isolates the possible impairments as a result of solid water in the atmosphere.

The resulting equation can be used to obtain the attenuation due to clouds for a given location.

$$\gamma c(W, F, T) = KiW \quad dB/km$$

Where W= content of liquid water (g/m^3)

K =specific attenuation by water droplets

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

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

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

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

$$\varepsilon_o = 77.67 + 103.3\,(\frac{300}{T} - 1)$$

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

$$F_s = 590 - 1500\,(\emptyset - 1)$$

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

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

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

IV. Result

The above equations where solved using Microsoft excel software. The tables below show the extracted data from the computed equations and these tables are used to generate the graphs. The cloud liquid water content is extracted from Table 1 to continue the computation for cloud attenuation after specific attenuation by water droplets has been achieved for temperatures of 0^{o}C and 30^{o}C respectively. The results of the model is shown as follows.

Table 2: Showing Cloud attenuation at cloud water content of 1g/m^3

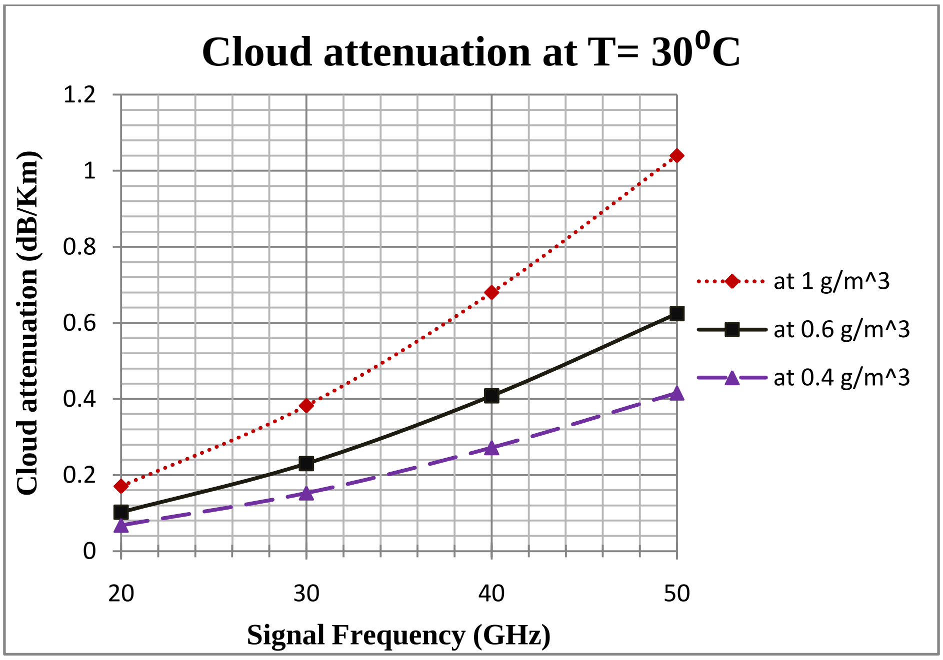
F (GHz)	Cloud attenuation A (dB/Km)at water content of 1 g/m^3	
	At T= 0^{o}C	At T= 30^{o}C
20	0.83	0.17
30	1.46	0.382
40	2.02	0.68
50	2.46	1.04

Table 3: Showing Cloud attenuation at cloud water content of 0.6 g/m^3

F (GHz)	Cloud attenuation A (dB/Km)at water content of 0.6 g/m^3	
	At T= 0^0C	At T= 30^0C
20	0.4	0.102
30	0.876	0.23
40	1.212	0.408
50	1.476	0.624

Table 4: Showing Cloud attenuation at cloud water content of 0.4 g/m^3

F(GHz)	Cloud attenuation A (dB/Km)at water content of 0.4 g/m^3	
	At T= 0^0C	At T= 30^0C
20	0.332	0.068
30	0.584	0.153
40	0.8	0.272
50	0.984	0.416



V. Conclusion

This paper examines the impact of cloud attenuation at Ka (30/20GHz) and V (50/40GHz) frequencies on earth space path for links to Nigerian Communication satellite. Cloud attenuation due to cloud liquid water contents has been obtained using the equations above. Thegraphical relationship is obtained between different frequencies and attenuation over the frequency range 20 to 50GHz gives an estimate of Cloud contribution to signal attenuation at temperatures of 0^oC and 30^oC and also when cloud liquid water content is within 1, 0.6 and 0.4 g/m^3.

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Ehikhamenle M "Effective calculation of Cloud Attenuation on Satellite Communication Systems in Nigeria based on Cloud Type." IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) 13.3 (2018): 12-16.