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AN ESTIMATE OF INTERFERENCE EFFECT ON HORIZONTALLY POLARIZED SIGNAL TRANSMISSION IN THE TROPICAL LOCATIONS: A COMPARISON OF RAIN-CELL MODELS

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Abstract—With the recent growth in the use of satellites for an increasing range of devices, services, applications and users, there is a need to optimize the signal received for availability, reliability and tolerance to interference. A lot of prediction models have been used in recent times to estimate intersystem interference due to hydrometeor scattering on vertically polarized microwave signals into the receiver of earth-space communications systems operating at the same frequency. The horizontal polarization is usually not investigated because coupling between the transmitting and receiving systems is much less than in vertical polarization. Much as this is true in the temperate regions, the nature and characteristics of tropical rainfall which are quite distinct from the temperate rainfall, means that the horizontal polarization when transmitted should be investigated for hydrometeor induced interference in tropical regions. This present work computes transmission loss on horizontally polarized signals based on two models (Awaka and Capsoni). The results obtained are compared and it is observed that there is only a difference of 1 dB in the transmission loss between the models. However, at higher frequency (> 20 GHz), the Capsoni model does not produce values for the transmission loss L, while Awaka model predict a low interference at various antenna gain for percentages of time $> 0.1\%$.

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1. INTRODUCTION

The continuous interest in the use of satellites for provision of telecommunication and information networks can not be overemphasized, as many banks, security agents, internet users, fixed and mobile telephoning among others are strongly attached to satellite link. Most people of the developing countries are still far behind in the utilization of the unlimited services provided by communication satellites. In Sub-Saharan Africa and some developing countries, the quality of signals received is often affected by high intensive rainstorms that are characterized by large size raindrops on the path of communication satellite [4, 6].

Due to the increased usage of terrestrial microwave relay link for technological developments, there is a frequency sharing between the existing and new services in order to decongest the crowded spectrum. This has led to amount of pressure on the limited bandwidth available at the lower frequencies. At frequencies above 10 GHz, the use of the terrestrial and earth satellite radio links has been established due to the aforementioned problem. However at those frequencies, the most serious problems in system design emanated from attenuation, depolarization and scattering interference by precipitation particles along the radio path [11]. This interference is usually lead to a decrease in the signal-to-noise (S/N) ratio at the satellite terminal. At SHF and EHF, scatter by hydrometeors in the atmosphere can become the dominant interference mechanism for an earth-station antenna pointed in the opposite general direction. Hence, the main concern for systems designers and service providers is signal interference. Interference hampers coverage and capacity, and limits the effectiveness of both new and existing systems. It is an unavoidable fact that wireless communications systems must coexist in extremely complicated signal environments. The frequency of an interfering signal is the most common parameter leading to the identification of the interfering source [11]. Thus, an interference problem can often be categorized by its frequency characteristics. The amount of interference received in a communication channel depends on several factors such as the path geometry, electrical parameters of the transmitting and receiving systems, and the meteorological variables associated with the propagation medium among several others.

The critical role of the Interference to communication systems has been the concern of many organizations like, International Telecommunication Union (ITU), the International Radio Consultative Committee (CCIR) and European cooperative program COST 210 among others. They all guide the Radio regulations across the international boundaries [19]. Despite the level of work that already carried out on the evaluation of bistatic interference on communication paths at the temperate region, among such studies are [9–11, 15, 16, 19, 22] to mention but few; the results obtained in such studies can not be applied directly on tropical paths. This is due to the nature and characteristics of tropical rainfall which are often convective, and characterized by large raindrop sizes, of high intensity and often times accompanied by severe lightning and thunderstorm. In the tropical region, few efforts have been made to investigate the problem using radio-climatological parameters from Nigeria, to predict interference levels on propagation paths in the region [1, 5, 7, 18]. While [4, 6, 20] computed the transmission loss based on the radio-climatological parameters from Kenya and Cameroon and the results in these locations are compared with those for Nigeria. All these researchers used one model or the other to estimate transmission loss arising from hydrometeor scattering on vertically polarized microwave signals into the receiver of earth-space communications systems operating at the same frequency. The horizontal polarization is usually not investigated because coupling between the transmitting and receiving systems is much less than in vertical polarization. Much as this is true in the temperate regions, the nature and characteristics of tropical rainfall (high intensity, large raindrop size etc) which are quite distinct from the temperate rainfall, means that the horizontal polarization when transmitted should be investigated for hydrometeor induced interference in tropical regions.

This present work is based on the improved Awaka model [9] to evaluate the impact of intense rainfall on the transmission signal in horizontally polarized signals in the tropical region and the results obtained are compared with the Capsoni exponential rain cell model [12].

2. THE SIMPLIFIED RADAR EQUATION AND INPUT PARAMETERS

The path geometry of 'hydrometeor scatter' interference is usually defined in terms of the station separation, their projection to the common volume and also their relative bearing. The details of these variables, their common volume heights and the horizontal extents can be obtained from the work of *Ajewole and Ojo* [6]. The sketch of typical 'hydrometeor scatter' propagation geometry from a terrestrial system to an Earth-Space system is depicted in Figure 1.

The result of 11.6 GHz radiometric experiment for the cumulative distribution of point rain rate measured under the joint African radiometric measurement campaign in Ile-Ife, Nigeria (4.34°E, 7.33°N)

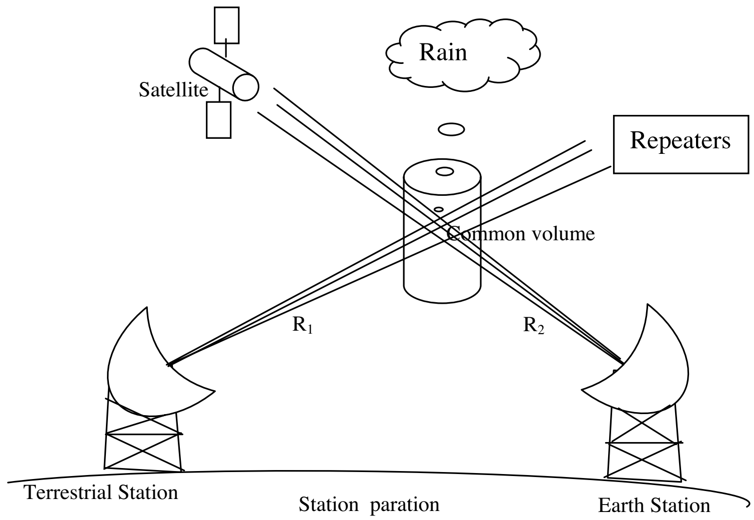

Figure 1. Rain scatters geometry.

is used in this study [18].

Taking into consideration of the contribution from the elementary volume forming the common volume as illustrated in Figure 1, the Radar equation can be simplified in terms of the transmission loss L, as

$$L = P_t - P_r = K_T + A_g - M + (S - Z + A) \tag{1}$$

All the terms in Equation (1) are in decibel (dB) units. A_g is the extra attenuation due to gaseous absorption, M is the polarization decoupling factor, S is the allowance for Raleigh scattering at frequencies greater than 10 GHz, and A is the slant path rain attenuation from the transmitter to the common volume and from the common volume to the satellite receiver. This is calculated using the power law relationship between the rain rate and the attenuation, and it can be expressed as

$$A_H = k_H R^{\alpha_H} \tag{2}$$

The subscript H refers to the horizontal polarization and the constant parameters k_H and α_H for calculating attenuation A are shown in Table 1 for the frequencies investigated in this study. The scattering cross section (σ_{bi}) of each single particle can be evaluated numerically using the complete Mie solution or Rayleigh approximation and this is related to the radar reflectivity of Equation (1) as

$$\sigma_{bi} = \left(10^{-18}\right) \frac{\pi^5}{\lambda^4} \left| \frac{\varepsilon - 1}{\varepsilon + 2} \right|^2 Z \tag{3}$$

where λ is the wavelength in meters, ε is the permittivity of the medium (that is frequency, temperature, and particle phase dependent) and Z ($\mathrm{mm^6 m^{-3}}$) is the radar reflectivity factor which is of the form $Z = \log z$, where z can be calculated by using a power law relation of the form

$$z = aR^b \tag{4}$$

where R is the rainfall rate (mm/h). In this study, the generalized raindrops size distribution of Ajayi and Olsen is assumed, and since the distribution fits the convective thunderstorm rain type very well, the Z-R relationship proposed by *Ajayi and Owolabi* [3], for tropical thunderstorm rain in which $a = 461$ and $b = 1.31$ respectively is assumed.

Table 1. Regression coefficients k and α of the power law expression for thunderstorm rain type for water temperature of 20°C [8]. H represents horizontal polarization states.

Frequency (GHz)	k_H	α_H
4.0	6.51×10^{-4}	1.072
6.0	1.85×10^{-3}	1.214
8.0	4.72×10^{-3}	1.273
10.0	1.10×10^{-2}	1.252
12.0	2.20×10^{-2}	1.204
16.0	4.10×10^{-2}	1.128
20.0	8.20×10^{-2}	1.083
35.0	2.76×10^{-1}	0.970

The term K_T in Equation (1) takes the form,

$$K_T = 10 \log \left[\frac{G_1 G_2 \pi^2}{64^3 \lambda^2} \left| \frac{m^2 - 1}{m^2 + 1} \right| \times 10^{18} \int_c \frac{F_1(\vartheta_1, \varphi_1) F_2(\vartheta_2, \varphi_2)}{R_1^2 R_2^2} dv \right] \tag{5}$$

where G_1 and G_2 are the antenna gains, m is the complex refractive index of water, λ is the wavelength of the wave, $F_1(\vartheta_1 \varphi_1)$ and $F_2(\vartheta_2 \varphi_2)$

are antenna directivity functions, R_1 and R_2 corresponds to the slant path length from the interfering terrestrial station and from the satellite station to the common volume respectively (Figure 1) while dv is an elementary volume.

The study also covers the frequency range 4–35 GHz used presently by most service providers for terrestrial and Earth-space communications and the transmission loss is evaluated for probability of occurrence ranging from 1–10^{-3}%. Additional input parameters used in the computation procedure are, the elevation angle of the interfering terrestrial microwave system, which is 1°, having a beamwidth of 1.6° and antenna gain which varies from 35–55 dB. The satellite system is assumed to have elevation angle of 55°, beam width 0.18° and a gain of 59 dB. The vertical structure of precipitation is assumed constant up to the 0°C isotherm height, below which is the rain region where attenuation and scattering of the wanted and the interfering signals occur. Beyond the 0°C, is the ice region where Z decreases at the rate of 6.5 dB/Km. In Nigeria and during raining conditions, the mean freezing h_{FR} is nearly constant and so equal to h_0. Its value lies between 4.54–4.79 km. An average water vapor density of 20 g/m^3 was assumed in the study [17] while a water temperature of 20°C was assumed to calculate the refractive index of water using the method describe by *Ray* [21].

The rain cell has a cylindrical symmetry within the horizontal cross section; the rainfall rate is assumed to vary exponentially with peak intensity inside the rain cell and is expressed as

$$R(r) = R_M e_0^{-r/r} \tag{6}$$

where r_0 is the radial distance from the rain cell center, R_M is the maximum rainfall rate and r_0 is the parameter characterizing the cell size. For Capsoni and Awaka rain cell models r_0 is expressed respectively as

$$r_0\left(R_M\right) = 1.7\left[\left(\frac{R_M}{6}\right)^{-10} + \left(\frac{R_M}{6}\right)^{-0.26}\right] \text{km} \tag{7}$$

$$r_0\left(R_M\right) = \frac{10 - 1.5\log_{10} R_M}{\ln\left(\frac{R_M}{0.4}\right)} \text{km} \tag{8}$$

Equation (7) is the basis of the present study for horizontally polarized signal. The probability of occurrence of a rain cell is defined in terms of the total number of rain cells $N(R_M)$ for a given area per unit rain rate $R(r)$. A general retrieval algorithm for N as proposed by Awaka can be expressed as

$$N^* (R_m) = \frac{-1}{4\pi R_m r_o (R_m)} \left| \frac{d^3 P(R)}{d (\ln R)^3} \right|_{R=Rm} \tag{9}$$

For the Capsoni model, the denominator of the first term on the right is two times higher. By using the third-order differentiation, this equation is solved in terms of a power law relationship for the cumulative distribution of measured rain rate $P(R)$ at the location of interest as

$$P(R) = P_o \ln \left(\frac{R'}{R} \right)^k \quad 0 < R < R'. \tag{10}$$

P_o and k can be obtained by interpolation from cumulative distribution of the measured point rain rate $P(R)$. R' is normally assumed to be about four times the highest rain rate at the location of interest.

3. RESULTS AND DISCUSSIONS

The simplified Awaka 3D rain cell has been employed to estimate the cumulative distribution of transmission loss, L for terrestrial station path lengths to common volume distance, ranging from 50 to 250 km for horizontally polarized signal, and the results been compared with Capsoni model. The equivalent common volume, CV height correspond to each terrestrial propagation path length was found to be the same as those computed for vertically polarized signal. As earlier reported in the work of *Ajewole and Ojo,* [4], at station separation >200 km, the CV is in ice region, it is only the wanted signal that will be affected by the attenuation.

Figure 2 shows the influence of varying the station separation on the computed transmission loss, at percentages times ranging from 1% to 0.001%, frequency of 16 GHz and terrestrial station gain of 45 dB. The result show that, for the two models the cumulative distribution of transmission loss increases gradually with increasing antenna. This implies less interference in the satellite receiving system. This process was observed at other frequencies, but when the station separation is longer than 204 km, the slope of the curve of transmission loss for the various percentages of time becomes steep due to the decrease in radar reflectivity factor in the ice region. The transmission curve for Awaka model varies from about 121.26 dB to 164.33 dB while it is 122.26 dB to 165.33 dB for Capsoni model. This shows a difference of 1 dB for the two models.

Figure 3 also show a typical graph of cumulative distribution of transmission loss against station separation for 0.01% of time at various

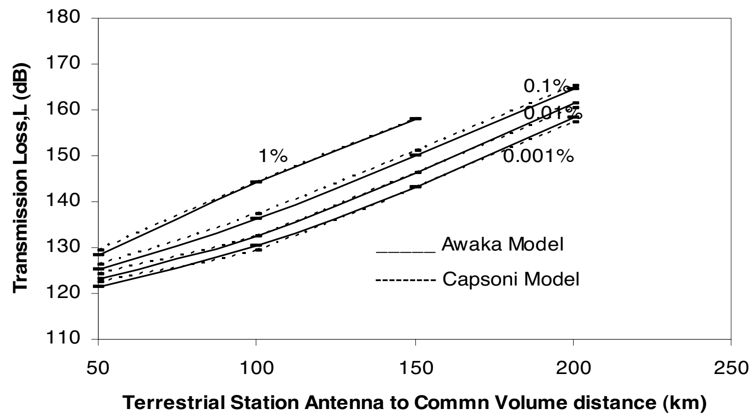

Figure 2. Comparison of the cumulative distribution of transmission loss with TS-CV at varying percentages of time, frequency 16 GHz and terrestrial antenna gain of 45 dB.

frequencies. In all the frequencies considered for this percentage of time there is a significant differences of 1 dB between the models mostly at path length > 200 km. The dependence of transmission loss on frequency at various percentages of time is also investigated for the two models. Figure 4 is a typical graph for short path length. The results show a slight decrease in transmission loss at frequencies ≤ 10 GHz but rises thereafter up to the frequencies ≤ 16 GHz for the two models. At frequencies greater than 20 GHz, the transmission loss is significantly higher in the earth station receiver terminal than at other frequencies due to strong path length attenuation and due to the rapidly decreasing radar reflectivity in the ice region at 250 km (though not shown here, the latter could be observed at long path length).

It could also be observed that even at higher frequency of 34.5 GHz, the Capsoni model does not produce values for L; this may be due to the practical limit set for the computation, for coupling usually around -180 dB and so the computation rejects any lower values. An obvious implication of this effect for horizontally polarized signals along tropical propagation is that, Awaka model could be preferred for computation under such condition.

The results of variation of cumulative distribution of transmission loss with terrestrial antenna gain at frequency of 16 GHz, satellite station elevation angle of 55° and terrestrial station to common volume distance for both short and long path lengths is presented in Figure 5. Generally, the transmission loss decreases (increase in interference levels) with increasing terrestrial antenna gain for the two models.

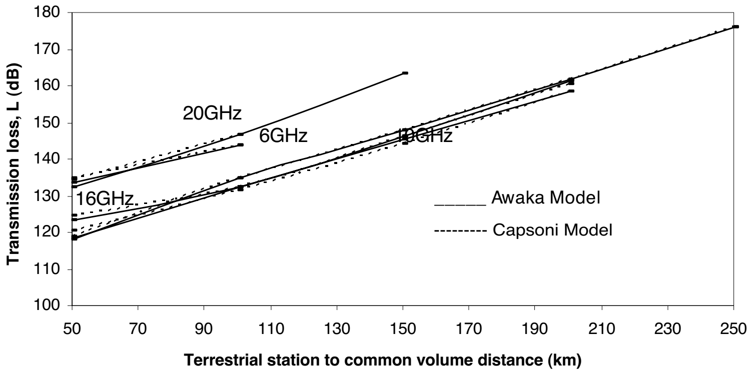

Figure 3. Comparison of the transmission loss with terrestrial antenna station to common volume distance, 0.01% of time and varying the frequencies.

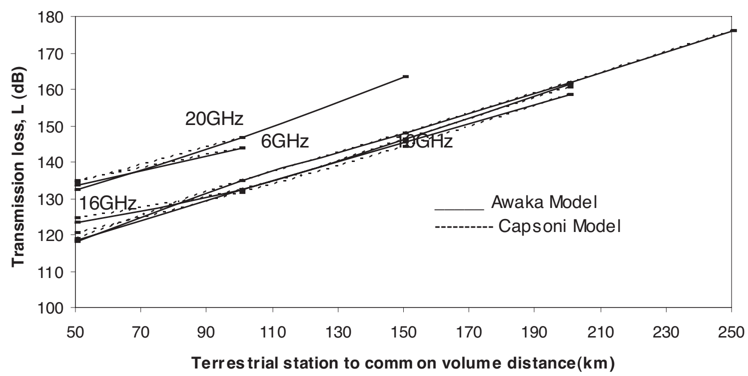

Figure 4. Variation of the transmission loss with frequency, terrestrial antenna station to common volume distance of 50 km (short path length) and varying percentages of time.

It could also be observed that at short path length, Capsoni model is higher by 1 dB for all the percentages of time observed, while at long path length, this was only noticed for 0.1% of time, and Awaka model lead by 1 dB for percentages of time $> 0.1\%$. Hence, Awaka model predicts a low interference at various antenna gain for these percentages of time. The results of variation of the transmission loss with % of time, terrestrial antenna to common volume distance of 200 km (long path length) and varying the frequencies (Figure 6) show that both models could not produce valuable results for frequencies larger than 16 GHz for horizontally polarized signal due to the practical limit set for the computation for coupling usually around −180 dB, and so the computation rejects any lower values (though not shown here, this is not so for short path length of 50 km). However, there is need for experimental validation through concurrent measurement of transmission loss and attenuation to confirm these results.

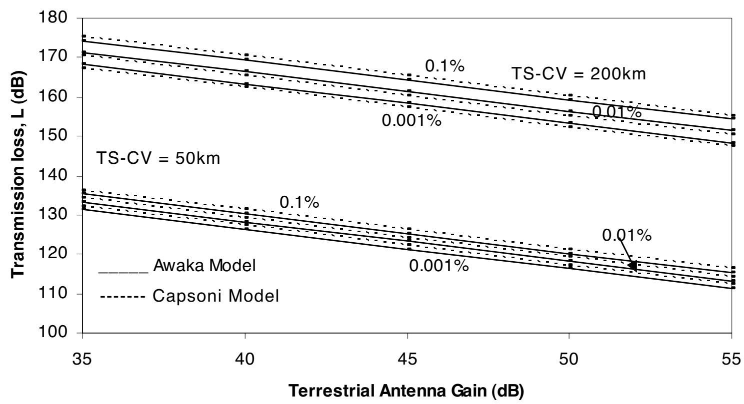

Figure 5. Variation of cumulative distribution of L with terrestrial antenna gain at frequency of 16 GHz, satellite station elevation angle of 55° and TS-CV distance of 50 km and 200 km at various percentages of time.

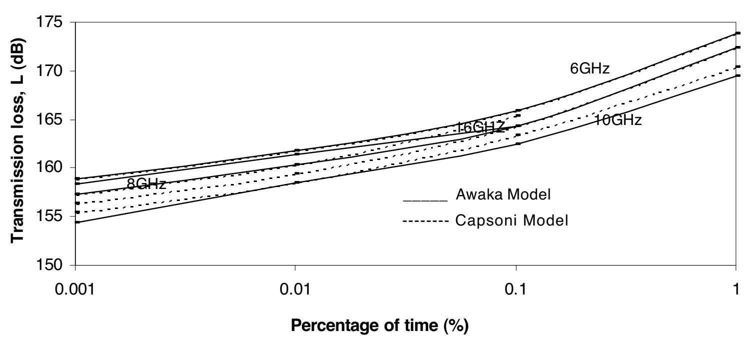

Figure 6. Comparison of the transmission loss with % of time, terrestrial antenna to common volume distance of 200 km (long path length) and varying the frequencies.

4. CONCLUSION

Two models have been compared to justify the need for the computation of cumulative transmission loss for horizontally polarized signals at the tropical locations. There is only a difference of 1 dB in the transmission loss between the models. However, at higher frequency (> 20 GHz), the Capsoni model does not produce values for L, while Awaka model predict a low interference at various antenna gain for percentages of time $> 0.1\%$. The results of the variation of the transmission loss with % of time, terrestrial antenna to common volume distance of 200 km (long path length) and varying the frequencies show that both models could not produce valuable results for frequencies larger than 16 GHz for horizontally polarized signal due to the practical limit set for the computation for coupling usually around -180 dB.

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