Rain rate and rain attenuation prediction for satellite communication in Ku and Ka bands over Nigeria.

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Abstract

Rain rate and rain attenuation predictions are one of the vital steps to be considered when analyzing a microwave satellite communication links at the Ku and Ka bands. In this paper, tools for the prediction of rain rate and rain attenuation are presented in the form of contour maps for Nigeria using a massive rainfall data bank of 30 years which are taken from measurements made from the coast to the arid region of Nigeria. Rain-rate maps for the country of Nigeria were developed using the models purposely designed for tropical zones while ITU-R models were used for the rain-attenuation maps. The information from these maps will be a good preliminary design tools for both terrestrial and earth-satellite microwave links and also provide a broad idea of rain attenuation for microwave engineers

1. Introduction

Atmospheric effects play a major role in the design of satellite- to-earth links operating at frequencies above 10GHz. Raindrops absorb and scatter radio waves, leading to signal attenuation and reduction of the system availability and reliability. The severity of rain impairment increases with frequency and varies with regional locations [1]. Hence the incidence of rainfall on radio links becomes even more important for frequencies as low as about 7 GHz particularly in the tropical and equatorial climates, where intense rainfall events are common [2]. It is therefore very important when planning both microwave and terrestrial line-of–sight system links; to make an accurate prediction of rain induced attenuation on propagation paths [3]. Initially, attenuation prediction attempts involved extrapolation of measurements to other locations, frequencies, and elevation angles; however, the complex nature and regional variability of rain make this approach highly inaccurate [4]. An empirical methodology of predicting rain attenuation require 1 min rain rate, which is still scarce in tropical region-Nigeria [5]. A method for converting the available rain rate data to the equivalent 1-minute rain rate cumulative distribution is therefore necessary.

The aim of this paper is to give additional tools to the system designers, in the form of contour maps of rain intensity and rain attenuation, for the design of satellite systems in the tropical countries and particularly in Nigeria. Nigeria has recently launched her first communication satellite, known as Nigerian Communication Satellite (NIGCOMSAT-1). It is the first Africa geosynchronous communication satellite and is positioned at 42.5^0 E. NIGCOMSAT-1 has an expected service life of 15 years and can operate at C, Ku, Ka and L band. It is committed to effective delivery of secure, qualitative and value-added satellite services to Africans, while the Ka-band transponders will also cover part of Italy. Nigeria is expected to launch another satellite communication (NIGCOMSAT-2) in the year 2010. Hence the tools from this work will be used for preliminary design of the satellite microwave links, satellite–payload design (satellite-coverage analysis), Earth –segment design and a broad idea of rain attenuation for microwave engineers. The tools are also applicable to other regional and hemispherical broadband access systems.

The climatic mapping of rain-rate and rain-attenuation has naturally attracted a great deal of attention- for instance this kind of work has earlier been carried out for USA [6], Europe [6,7-8], Malaysia [6], Colombia [9] and on global scale by [10, 11-12]. Efforts has also been made by Ajayi and Ofoche [5] to obtain 1 minute rain rate map for Nigeria using Rice-Holmberg model however the model overestimates rain rates in the high-availability range (0.01%), and underestimates in the range between 0.1% to 1% [11]. These percentages unavailability of time are crucial for communication purposes, hence the need for this work [13].

2 Rain-Rate Prediction Models

Several models exist for the prediction of point rainfall-rate cumulative distribution, some of which has considerably influenced the zonal models of the ITU-R. Among are the works of Crane [12], Segal [3], and Rice – Holmberg [14] to mention but few. Recent analysis suggests that the rain rate distribution is better described by a model which approximates a log-normal distribution at the low rates, and a gamma distribution at high rain rate. This kind of model was developed by Moupfouma and Martins [15]. The model is good for both tropical and temperate climate. Moupfouma model requires three parameters; λ and γ which are coefficient factors and depend on the local climatic conditions and geographical features where in our case, λ = 1.066 and γ = 0.214 and $R_{0.01}$ which is the rain intensity exceeded during 0.01 percent of time in an average year (mm/h). To estimate $R_{0.01}$, Chebil's model appears suitable and it allows the usage of long-time mean annual accumulation, M, at the location [16]. The power law of the model is given by

$$R0.01 = \alpha M^{\beta} \quad (1)$$

where α and β are regression coefficients. Chebil has made a comparison between some models based on measured values of $R_{0.01}$ and M in Malaysia, Indonesia, Brazil, Singapore and Vietnam. He showed that his model is the best estimate of the measured data [16]. The regression coefficient α and β are defined as

$$\alpha = 12.2903 \quad \text{and} \quad \beta = 0.2973 \quad (2)$$

Thus, using the refined Moupfouma model and Chebil model, the 1 min rain-rate cumulative distribution is fully determined from the long-term mean annual rainfall data.

3 Rain-Attenuation Prediction Model

A number of rain attenuation prediction models have been published which claim global applicability. Details of these models can be obtained from COST 255 [17].

To develop the map for rain attenuation over Nigeria, ITU rain attenuation model of ITU P.618-8 was used [10]. It has been reported that the ITU rain attenuation prediction model result were close to the average prediction of a set of results obtained from the application of eight different methodologies [18]. The procedure for step-by-step calculation of the model is omitted in this report, but can be obtained from [10]. However, the input parameters needed for the model are, point rainfall rate for the location for 0.01% of an average year (mm/h), height above sea level of the Earth station (km), elevation angle, latitude of the Earth station (degree), frequency (GHz) and effective radius of the Earth (8500 km).

4. Development of Rain-Rate and Rain Attenuation Contour Maps

Daily rainfall data were collected from the Nigerian Meteorological Station for 26 locations which cut across the coastal to arid region of Nigeria for a period of 30 years for most of the stations. The south-south area is the coastal region with an annual average rainfall of about 3000 mm; the south west of the country belongs to the rain forest zone, with an average accumulation of 1500-2000 mm. The middle belt region also receives about 1200 mm, while the northern area is the arid/savannah region, with an average accumulation less than 1000 mm.

4.1 Rain Rate Contour Maps

For the development of rain rate contour map, we have used Moupfouma model in conjuction with the Chebil's model of eqn. 1 and 2. Thus, by applying the Moupfouma model and using the mean annual accumulation of each location as input, the 1 min rain-rate contour maps for 0.1% (Fig.1) and for 0.01% (Fig.2) were developed. The contour lines were developed using the kriging method in a MATLAB program. ITU-R has classified Nigeria to be in rain climatic zone N and P and it has assigned a value of 65 mm/h and 145 mm/h for $R_{0.1}$ and $R_{0.01}$ respectively for a location like Warri and Calabar (coastal region) which belongs to zone P of the ITU. However, Figure 2 and 3 shows that in such location, $R_{0.01}$ is ~ 130 mm/h, while it is ~ 50 mm/h for $R_{0.1}$. For area with lower average annual precipitation (arid area), $R_{0.01}$ ranges from about 65 – 80 mm/h depending on the location while $R_{0.1}$ is ~ 30 mm/h. However, ITU has assigned a value of 95 mm/h for $R_{0.01}$ and 35 mm/h to such area [19]. The mountainous zone like Jos Plateau with an altitude up to 1400 m has ~ 100 mm/h for $R_{0.01}$, while it is ~ 36 mm/h for $R_{0.1}$. The fact that ITU-R rain zoning overestimated rain rate values in Nigeria is clearly revealed with the help of this map [20].

4.2 Rain Attenuation Contour Maps

Application of ITU P.618-8 model consists of three methodologies: first is the calculation of the specific attenuation [21]; second, the calculation of rain height [22]; and third, the attenuation-calculation methodology [10]. The attenuation contour maps were developed for Ku and Ka band in order to meet today's active challenges in the rapid growth of satellite broadband networks. Efforts are being made to use Ka band rather than Ku band frequencies, due to the bandwidth requirements of the application they are expected to support. In addition Ka-band allow for a higher return-link data rate. In order to develop the rain attenuation for 0.1% and 0.01% of the time, rain rate from each contour line were applied to the ITU rain attenuation model in conjunction with the altitude and the latitude of each station. Other parameter used to draw the maps are; frequency of operation: 12.675 GHz for Ku and 19.45 GHz for Ka-band (these values were used because it corresponds to the center of the band for Ku and Ka-band downlinks respectively); Satellite orbital position: 42.5^0 E (NIGCOMSAT 1 orbital position).

Figure 3 presents the contour map for 0.01% rain attenuation for Ku-band over Nigeria, while Figure 4 is for Ka-band. The results show a difference in both the Ku and Ka-band predicted attenuation values over each of the location. For a coastal region like Calabar with the highest average annual accumulation, the rain attenuation is as high as ~37.8 dB for ka-band, while it is ~19.6 dB for Ku-band, this show a difference of about 18.2 dB between the two frequency bands. The results of the rain attenuation prediction in the south western part of the country (area regarded as the rain forest zone) has a difference of ~3 dB when compared with the coastal region for the Ku -band, while it is ~ 6 dB for the Ka-band. The middle belt region shows a difference of ~ 5 dB for Ku-band when compared with the arid region of the country, while it is up to ~ 10 dB for ka-band. The magnitude of the average difference between the far Northern zones (desert area) was of the order of 1 dB for Ku-band and 2 dB for Ka-band.

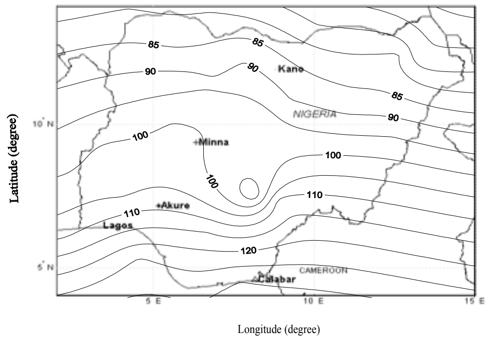

Figure 1: Rain rate (mm/h) maps for 0.01% of time

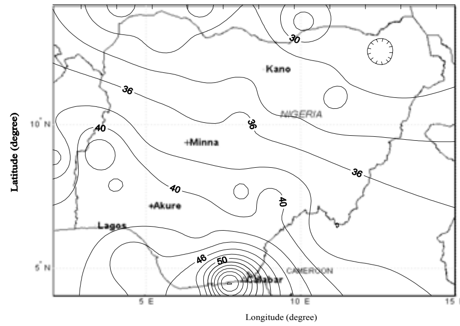

Figure 2: Rain rate (mm/h) maps for 0.1% of time

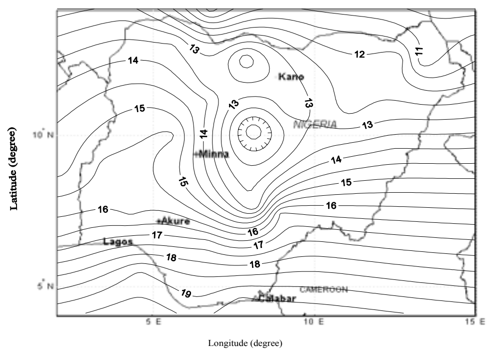

Figure 3: 0.01% rain-attenuation (dB) map for Ku band

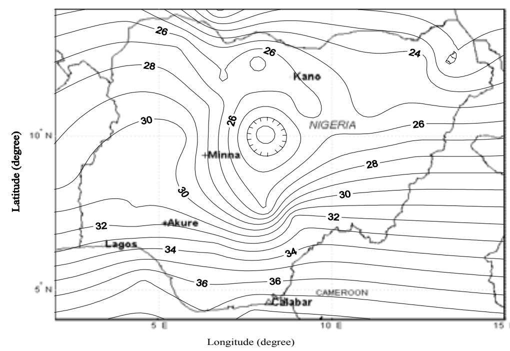

Figure 4:0.01% rain-attenuation (dB) map for Ka band

Figure 5 and 6 also show the contour maps for 0.1% rain attenuation for Ku-band and Ka-band respectively. This section is very crucial to system designers, since it corresponds to an average-year propagation objective (99.9 availability of time). For Ku band, the magnitude of the attenuation prediction was of the order of 1 dB difference for the coastal region of the country due to the higher rain rates used as input data. However, for Ka band the magnitude is as high as 7 dB when compared the coastal region with other zones. The northern part of the country showed a moderate rain attenuation prediction due to low amount of rainfall intensity in the region. In general, predicted rain-attenuation value is lower for Ku-band when compared with the Ka-band. There is consistence larger increase in the rain-attenuation prediction in the southern part of the country and inferior in the northern part. Hence, system designers need to be aware of these differences because they represent an uncertainty in the design of each link. The uncertainty might lead to an over-cost, both in initial expenses and in periodic expenses [9].

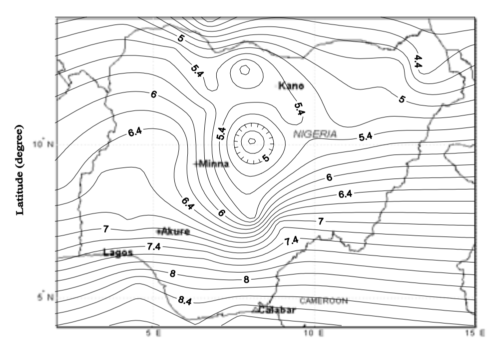

Figure 5: 0.1% rain-attenuation (dB) map for Ku band

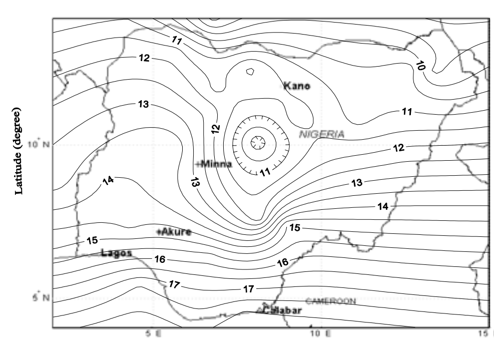

Figure 6: 0.1% rain-attenuation (dB) map for Ka band

5. Conclusions

Rain rate and rain attenuation contour maps have been developed for 0.1 and 0.01% of the time using the refined Moupfouma model for rain rate maps and ITU-R 618 for the rain attenuation maps over Nigeria. The 0.1% of time of rain attenuation is needed for very small aperture terminal (VSAT) network service-availability. The information from these maps will be useful in the preliminary design for both terrestrial and earth-satellite microwave links, and to provide a broad idea of rain attenuation to microwave engineers for the proposed launching of another satellite communication (NIGCOMSAT-2) in Nigeria.

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