

Analysis of Satellite Transmission Losses Due to Tropospheric Irregularities in Guinea Savanna Region of Nigeria

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Abstract

This paper presents results on the analysis of satellite transmission losses due to tropospheric irregularities in Guinea Savanna region of Nigeria. The analysis was based on measured rain rates data, signal strength, and quality of the Ku-band satellite signal during rainfall over the region. Five months (June to October, 2017) data was used to describe the monthly variation of precipitation intensity which was further used to estimate the propagation losses on the Ku-band frequency (12.245 GHz) over the region. The Ku-band satellite signal and rain rate measurement were taken simultaneously with symbol rate of 27, 509bps and satellite elevation (orbital) was 036E. It was found that low precipitation intensity below 10 mm/hr has less effects on Ku-band propagation while high precipitation intensity above 20 mm/hr that prevail for more than 15 minutes causes high propagation loss over the region.

Keywords: Ku-band Frequency, Tropospheric Propagation, Signal loss, Guinea Savanna region.

Introduction

The troposphere is the lowest portion of the atmosphere. Most of the weather effects takes place in the troposphere. It contains 80% of the atmosphere's mass and 99% of its water vapor. The troposphere begins at ground level to a height of about 17 km. The temperature of the troposphere decreases with height (approximately 6.5⁰C per km) and saturation vapor pressure decreases with

decreasing temperature, the water vapor content of the atmosphere decreases strongly with altitude. The troposphere has irregularities in temperature, pressure, and water vapor content due to stratification and turbulence, and it is believed that these irregularities and their effects on electromagnetic wave propagation reduce

the strength and quality of the transmitted signal (Akhondi and Ghorbani, 2005).

The performance of all the satellite systems operating in the higher frequency bands essentially depends on this medium. Effects due to the ionosphere can be neglected at frequencies above 10 GHz but tropospheric effects cause signal degradation on earth-space paths for substantial percentages of time, which leads to reduction in the quality and availability of communication services. Some of the tropospheric propagation effects are attenuation, depolarization and scintillation. Tropospheric scintillation concerns rapid signal amplitude and phase fluctuation throughout a satellite link. It is caused by irregularities and turbulence in the first few kilometres above the ground, thereby affecting atmospheric refractive index measurement (Mandeep *et al.*, 2006).

When satellite signal is transmitted through a medium (in this case the troposphere) consisting of atoms and molecules, the signal interact with the medium through various processes among which are absorption of the signal, scattering of the signal, reflection of the signal, and refraction of the signal. The efficiency of the interaction is related to the amount of signal absorption. Changes in propagation velocity

due to this interaction results in a change in the signal direction, called refraction and is described by its index of refraction (Aloa, 2013). Small changes in refractive index are necessary to cause a significant change in electromagnetic wave propagation. By using the relationship between refractivity and refractive index, the refractive index can be derived in terms of total pressure, temperature, and water vapor concentration, as shown in equation (1). Variations of temperature and moisture in the propagation path cause local refraction of the signal, resulting in signal loss and increase of noise.

$$n = 77.6 \times 10^{-6} \left(\frac{p}{T} \right) - 5.6 \times 10^{-6} \left(\frac{e}{T} \right) + 3.73 \times 10^{-1} \left(\frac{e}{T^2} \right) + 1 \quad (1)$$

Where n is index of refraction, T is temperature ($^{\circ}\text{K}$), p is localized atmospheric pressure (mbar) and e is water vapor pressure (mbar) (Ezeh *et al.*, 2014).

The transmission loss is the sum of the terminal losses and propagation losses. The propagation loss is the total loss in signal strength between the antenna located at the transmitting antenna site and a similar antenna located at the receiving site. The long term media basic transmission loss in a forward tropospheric scatter path is

$$\begin{aligned} L_{bsr} &= 30\log F - 20\log D + F(\theta d) - F_o + H_o \\ &+ Aa \text{ dB} \end{aligned} \quad (2)$$

Where F is the transmitted frequency in megahertz and D is the distance in kilometers (Aloa, 2013).

It has been reported that at Ku-band, the transmission losses is less than 1dB during clear sky, but can be up to 10dB during raining condition and high cloud intensity (Anita and Niranjana, 2011). Due to the congestion of communication services at frequencies below 10GHz, there is an urgent need to utilize higher frequencies bands for satellite communication links (Durodola *et al.*, 2017). Therefore, this paper is aimed at studying satellite transmission losses due to precipitation variation and intensity as it affects satellite communication links; to determine its nature and its possible effects on the propagation of satellite signals in Guinea savanna region of Nigeria.

Materials and Methods

The measurement was carried out at the University of Jos Physics Laboratory, Plateau State with weather conditions shown in Table 1. Spectrum analyzer, digital satellite meter and computer system was used to obtain the Ku-band signal. The

The consequences of these tropospheric irregularities to satellite communication links are: loss of signal strength at the receiver, wastage of transmission power in a bid to overcome the tropospheric activities, total loss of signal at the receiver in extreme cases and unavailability of the satellite link for a great percentage of the time (Ezeh *et al.*, 2014).

In this paper, the analysis of tropospheric irregularities (variation in precipitation and cloud condition) affecting satellite communication links was presented. The analysis focuses on the time series of rainfall intensities, monthly variation of rainfall and variation in cloud density. The results of this analysis will enable satellite communication system designer to determine whether it is economically feasible to Set-up satellite system in the area in question and to also determine the optimum satellite transmission frequency at which there will be the least effect of rain variation and cloud density.

Ku-band satellite signal and precipitation measurement were taken simultaneously which helped in accurate observation and identification of signal losses during rainfall

and high cloud intensity. Davis Vantage Vue weather station was used to measure and record rain rate and other meteorological parameters at one minute integration time. The Davis weather station has an Integrated Sensor Suite which is co-located with the outdoor unit of the beacon setup that is, the offset parabolic antenna. Considering the

horizontal and vertical non-uniformity of rain structure, the measurement was taken for five months (June to October 2017) to describe the monthly variation of precipitation intensity which was used to estimate the transmission loss within the troposphere.

Table 1: Characteristics of the experimental site and specification of parameter for the Ku-band link.

Measurement site	Jos, plateau state (9.896⁰ N, 8.858⁰ E; 1192 meters)
Climate region of the site	Guinea Savanna
Max / Ave / Min Temperatures	29.8 ⁰ C / 22.8 ⁰ C / 17 ⁰ C
Satellite Name/ Number	Eutelsalat; W4/ W7 (DSTV Multi-choice)
Satellite signal frequency	12,245GHz
Symbol rate	27, 509bps
satellite elevation (orbital)	036E
Satellite Geo-station Lookup	037.3E
Antenna diameter	90cm
Rain Equipment / Integration time	Davis Vantage Vue Integrated Sensor Suite (ISS) weather station and Weather Link

Calculation of losses due to precipitation

The strength of satellite signal may be degraded or reduced under rain conditions. Most especially, radio wave above 10 GHz are subject to attenuation by molecular absorption and rain. Presence of rain drops

can severely degrade the reliability and performance of communication links. Losses due to rain effect is a function of various parameters including elevation angle, carrier frequency, height of earth station, latitude of earth station and rain fall rate. The primary parameters are drop-size

distribution and the number of drops that are present in the volume shared by the wave with the rain.

The propagation losses due to rain is given by

$$L = 10 \log \frac{P_o(0)}{P_r(r)} \quad (3)$$

Where P_o is the signal power before the rain region, P_r is the signal power after the rain region, r is the path length through the rain region (Aloa, 2013).

The propagation loss due to rain is usually expressed by specific attenuation γ in decibel per kilometer. Therefore, propagation loss is

$$L = \gamma L_r \quad (4)$$

Calculation of losses due to clouds

The losses due to clouds density and variation was calculated using the International Telecommunication Union Radio Propagation Recommendation (ITU-R, 2009). The specific loss within a cloud can be written as:

$$\gamma_c = K_l m \text{ dB/km} \quad (6)$$

Where γ_c is specific attenuation (dB/km) within the cloud, K_l is specific attenuation

Where γ is specific attenuation in dB/km and L_r is rain path length in km. base on ITU-R specific attenuation model, it is found that γ depends only on rainfall rate measured in millimeters per hour. From this model, the usual form of expressing γ is

$$\gamma = aR^b \text{ (dB/km)} \quad (5)$$

where a and b are frequency dependent coefficients (Aloa, 2013).

Propagation loss due to rain is a key limiting factor in using high frequency bands in satellite and terrestrial microwave energy. Very intense rain rate causes link outage if the rain drop size approaches half the wavelength of the signal in diameter.

coefficient (dB/km)(g/m³) and m is liquid water density in the cloud(g/m³)

Based on Rayleigh scattering, which uses a double-Debye model for the dielectric permittivity $\epsilon(f)$ of water, can be used to calculate the value of K_l for frequencies up to 1000 GHz (Aloa, 2013).

$$K_l = \frac{0.819f}{\epsilon''(1+\eta^2)} \text{ (dB/km)(g/m}^3\text{)} \quad (7)$$

Where f is the frequency (GHz), and

$$\eta = \frac{2+\epsilon'}{\epsilon''} \quad (8)$$

Results and Discussion

The variation of precipitation intensities and time series analyses of precipitation-induced losses during some rainy period were presented in figures 1 to 5. Figure 1 and 5 shows the low intensities of precipitation over short period of time which has less effect on transmitted signals when compared with results obtained from the spectrum analyzer. Figure 2, 3, and 4 shows results of rain event with high intensities on some

typical days. It was observed that rate above 20mm/hr which prevail for more than 15 minutes result to high signal loss. These results were in agreement with the observation that rain rates above 40 mm/hr cause significant losses on electromagnetic wave propagation (Ajayi, 1993) this is due to preponderance of large raindrops that breakup into a distribution of very small drop-sizes causing severe interference to satellite transmitted signals (Ajewole, 2003).

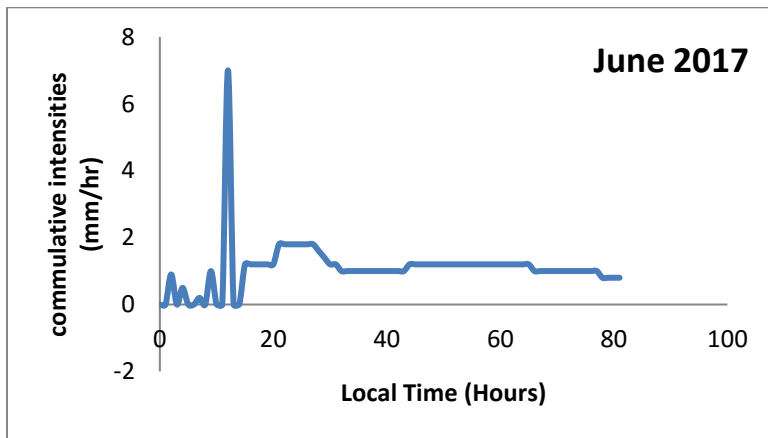


Figure 1. Monthly variation of precipitation intensity with time in Jos (2nd – 30th June, 2017)

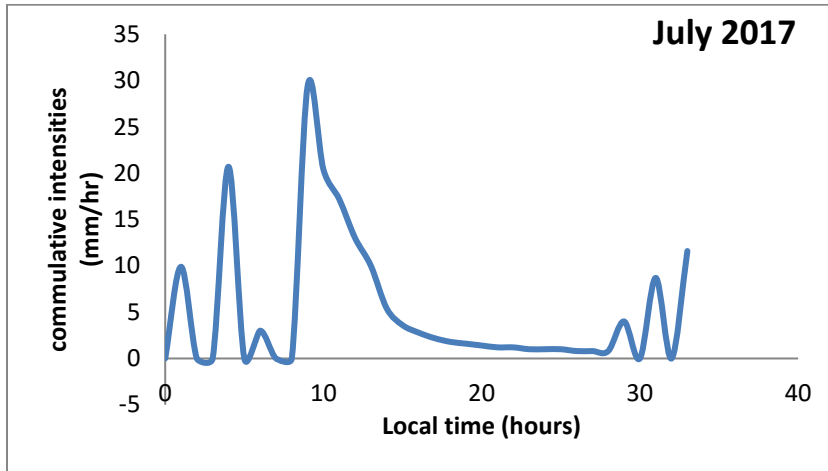


Figure 2. Monthly variation of precipitation intensity with time in Jos (1st – 29th July, 2017)

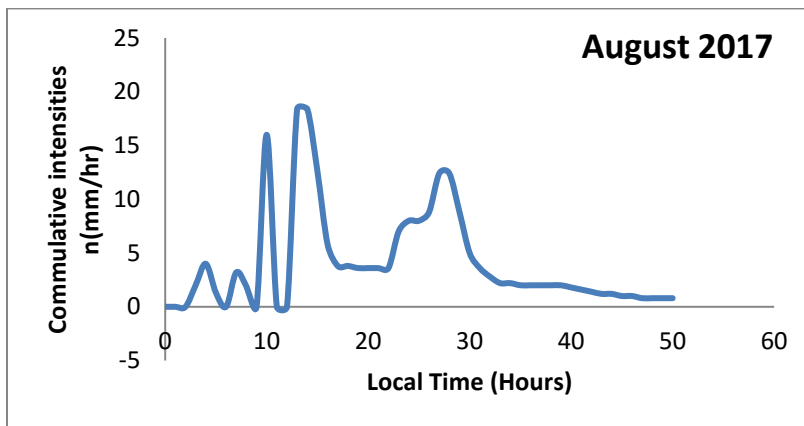


Figure 3. Monthly variation of precipitation intensity with time in Jos (1st – 30th August, 2017)

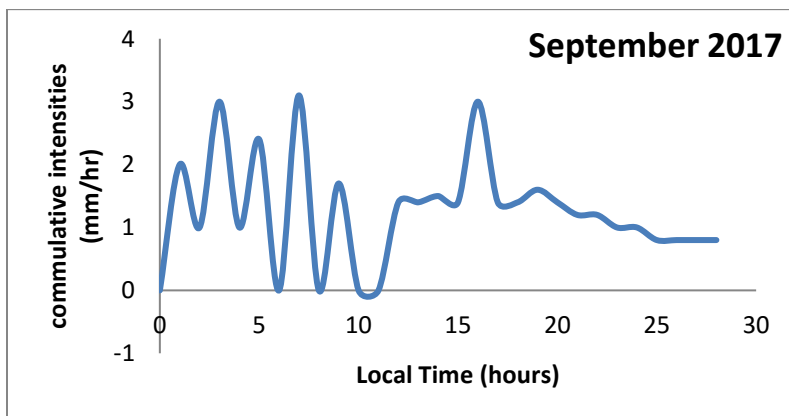


Figure 4. Monthly variation of precipitation intensity with time in Jos (2nd – 29th September, 2017)

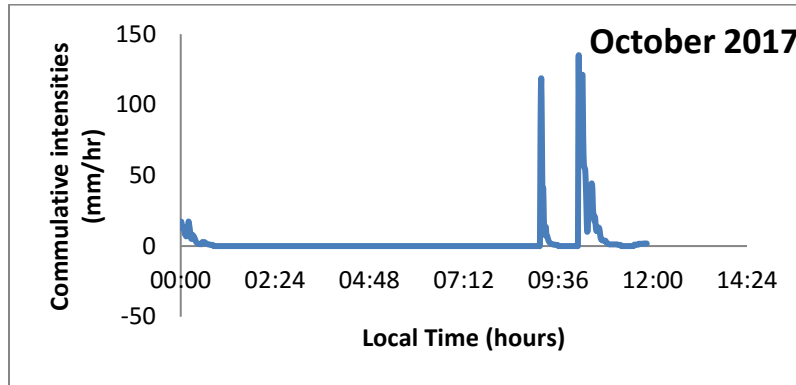


Figure 5. Monthly variation of precipitation intensity with time in Jos (2nd – 30th October, 2017)

Conclusion

The analysis of Satellite transmission losses due to tropospheric irregularities at the Ku-band frequency was obtained. Propagation loss is prevalent at frequencies above 10 GHz and increase with frequency. It was found that low precipitation intensity below 10 mm/hr has less effect on Ku-band propagation while high precipitation intensity above 20 mm/hr that prevail for more than 15 minutes causes high propagation loss over the region. This is because as frequency increases, the signal wavelength decreases and approaches the size of a rain drop. Therefore, giving the rain drop more scattering and absorption capabilities which affect the transmitted signal. The month of July, August, and

September were characterized by high intensity rain rates leading to high transmission power loss and pronounced reduction in the signal quality and strength over the Guinea Savanna region of Nigeria.

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