JOURNAL LA MULTIAPP

VOL. 03, ISSUE 03 (118-130), 2022
DOI: 10.37899/journallamultiapp.v3i3.671

Prediction of Gaseous Attenuation of Satellite Signal in Nigeria

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Article Info

Article history:
Received 15 May 2022
Received in revised form 16 June 2022
Accepted 18 June 2022

Keywords:
Geostationary
Radiosonde
Troposphere
Meteorological
Attenuation

Abstract

It would be noticed that the rate at which people are demanding for satellite services has drastically increased due to increment in population. However, one of the apprehensions of satellite telecommunication engineer is the effects imposed on the earth-to space path link by gaseous attenuation. The research conducted in this paper bordered about investigation with comparison of prediction models for gas attenuation in the six locations in Nigeria, with each of the location taken from six geopolitical within the country. The cities considered for the analysis are: Kaduna $(10.31^0\ N, 7.26^0\ E)$*, Lagos* $(6.45^0 N, 3.38^0 E)$*, Abuja* $(9.07^0 N, 7.39^0 E)$*, Portharcort* $(4.81^0 N, 7.0498^0 E)$*, Enugu* $(10.5^0, 5.76^0 E)$ *and Bauchi* $(10.30^0 N, 10.00^0 E)$*. Five-year radiosonde data were used in predicting gas attenuation in the cities selected which represent the geographical characteristics of each zone. Monthly variation of tropospheric components for each zone were computed. Influence of gas attenuation at different frequency bands for each zone were analysed. The results indicated that at clear-sky scenario, gas attenuation effects are still seen on satellite communication. Therefore, this research work would provide the needed statistical data of gas attenuation which would be of tremendous advantage for the link designers for their subsequent planning and design of good telecommunication systems in the six geopolitical zones of Nigeria.*

Introduction

Electromagnetic signals propagated in the atmosphere will experience a degradation (attenuation) because troposphere constituents present in the selected channel (air). The effects on the propagated signal could be minor or severe, depending on the following factors, viz: frequency of operation, temperature of the atmosphere, pressure values and water vapor concentration (Ippolito & Ippolito, 2017). Reduction of signal amplitude (attenuation) is basically caused through the several atmospheric disruptions such as rain, ice, snowflakes, fog, cloud, hail, atmospheric gases, among others (Crane, 2003; Hall, 1996). Among these disruptions, established fact reveals rain as the basic constituent for attenuation, while the others that may be regarded as additional factor leading to absorption, scattering and heating on the radio wave (Adimula, 1997), It is observed that, signal absorption occurs at quantum level shift in the rotational energy of the molecule, moreover, the occurrence takes place at a specific resonant frequency or at narrow band frequencies (Ippolito & Ippolito, 2017).

Signal attenuation parameters are to be critically examined under chosen weather condition. Among the atmospheric components with their respective percentages are highlighted as thus: Oxygen taking 21 %, nitrogen with 78 %, argon having 0.9 %, carbon dioxide with 0.1 % and water vapor with varied value of,~1.7 % at sea level and 100 % of relative humidity. However, both the oxygen and water vapor experience resonance frequencies in the bands of study, up to about 100 GHz, for space communication.

Magnetic dipole changes are involved in Oxygen absorption, however, absorption experienced by water vapor comprises of electric dipole transitions between the rotational states. Gaseous absorption is relying on atmospheric order, mostly, air temperature and water vapor content (Ippolito & Ippolito, 2017). Basic factors that affect signal deterioration of up-link and down-link links at C-band (6/4 GHz), Ku-band (14/12 GHz), Ka-band (30/20 GHz), and V-band (50/40 GHz) band is atmospheric gases (Ceaser, 2002).

At frequencies below 10 GHz, absorption lies at centimetres and millimetres wavelength due to oxygen and water vapor being negligible. However, the effect becomes noticeable at higher frequency bands as researched by (Ajayi et al., 1996). Fact established by (OJo, 2014) states that, rainfall incidence on radio link results to rain attenuation at 10 GHz in the temperate region, even though the effect is more significant when at frequency 7 GHz in the tropical and subtropical climates. Moreover, estimation of transmitted power and gain of the antenna on global broadband communication services requires consideration of absorption caused by oxygen and water vapor (Ojo, 2014).

Five-year radiosonde data was used by (Olla et al., 2019) for estimation of time percentage that a fade depth is eclipsed which is being used for estimation of outage probability caused by atmospheric multipath propagation and the value of point refractivity gradient obtained is dependent on geoclimatic factor. (Oluwafemi & Moses, 2021) estimated Geo-climatic factor (K) for six locations in Nigeria for improvement of future outlining of the radio links in the selected locations.

Effect of raindrop channels on the estimated rain rate and specific rainfall attenuation in Durban was investigated by (Adetan & Afulo, 2014). Gas attenuation was modelled for Ota, Southwest Nigeria where (Akinwumi et al., 2019) used five years' data extracted (April 2012 to December 2016) from Astra 2E/2F/2G Satellite link set at an elevation angle of 59.9º on 12.245 GHz. It was inferred that; gas attenuation has effect on earth-space satellite communication path during clear-sky scenario.

Cloud attenuation for Super High Frequency (SHF) and Extremely High frequency (EHF) applications was modelled by (Gustavo et al., 2015) It was inferred that the model could be used globally. In (ITU-R, 2013) cloud attenuation measurement data was obtained from station's spectrum analyser data for 2014-2017. Station integrated cumulative distribution for each of the existing cloud model was obtained from cloud attenuation distributions outputs from those data.

Methods

Materials and Methods

In order to have proper prediction of gaseous attenuation in Nigeria, a number of steps was involved which sprang from the collection of meteorological data from Nigerian Meteorological Agency (NIMET) to the prediction of gaseous attenuation.

Study Area

Nigeria with latitude and longitude $9.0820^0 N, 8.6753^0 E$ respectively is having total estimated land area of 923300 km^2 (Odekunle, 2004) Nigeria experiences two climatic seasons (raining and dry) in throughout the year. The two seasons experienced in the nation, raining (April to October) and dry (November to March). From June to September, the weather experienced is quite humid and raining. Nigerian climate is dominated by the influence of three major atmospheric phenomena, namely: the maritime tropical (mT) air mass, the continental tropical (cT) air mass and the equatorial easterlies. Over the country, the values for temperature are varied with respect to locations. The most clearly marked differences are between the coastal areas and the interior the high plateau and the lowlands. On the plateau, the mean annual temperature figures vary between 21℃ and 27°C. On the interior lowlands, the mean annual temperatures registered are over 27°C (Odekunle, 2004).

Meteorological data were collected from the following locations: (1) Kaduna ($10.31^0\ N, 7.26^0\ E$); (2) Lagos ($6.45^0 N, 3.38^0 E$); (3) Abuja ($9.07^0 N, 7.39^0 E$); (4) PortHarcort ($4.81^0 N, 7.08^0 E$); (5) Enugu ($10.5^0, 5.76^0 E$); (6) Bauchi ($10.30^0 N, 10.00^0 E$).

Each of the six locations was selected to represent geographical zones (South West, South East, North West, North East, South and North Central) comprising an area of similar climatic tendency in Nigeria.

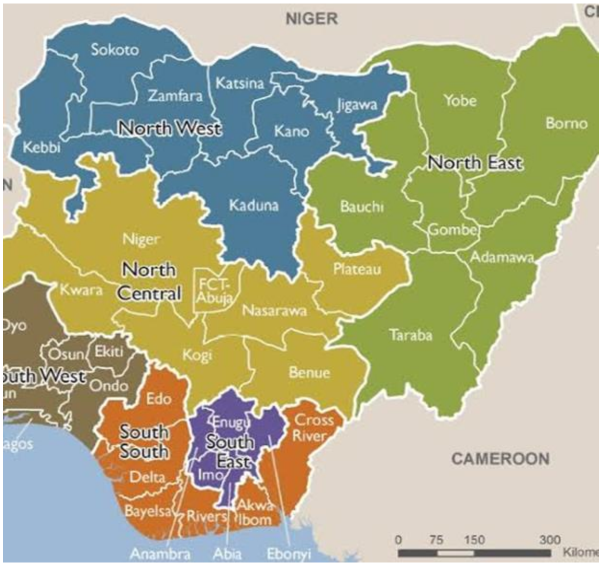

Figure 1. Map of Nigeria (Odekunle, 2004)

Estimation of Gaseous Attenuation

Attenuation due to atmospheric gases counts on frequency, elevation angle, and altitude above the sea level and water vapor contents. Its value is minima in comparison to rain attenuation. Attenuation caused by atmospheric gases is less than 0.01 dB/km at frequency below 10 GHz. The value starts to increase when the frequency is above 10 GHz. Water vapor and oxygen are the main contributors to gaseous attenuation in the frequency range within approximately (+ or – 15 %).

Quality of signal transmission is drastically degraded due to interaction between molecular gases and sunlight emission in telecommunication system (Elcev, 2005). Millimetre and sub-millimetre wave signals encounter scattering and absorption during propagation in the troposphere. These effects are caused by the presence of molecule of gases, water droplets and other atmospheric components (such as smoke and dust) (Harb, 2010).

Propagated signals in the atmosphere experience scattering and absorption due to the presence of tropospheric components such as pressure, relative humidity and temperature. Scattering and absorption is dependent on the transmission frequency of signals (Oluwafemi & Moses, 2021). In the transmission medium, water vapor and dry air elements usually bring about signal degradation.

It is worth mentioning that, water particles can either absorb or scatter electromagnetic waves compared to the presence of oxygen. For this reason, the simplified approximated model of gaseous attenuation was adopted from the techniques recommended in (ITU-R, 2013). The

ISSN: 2716-3865 (Print), 2721-1290 (Online)

various meteorological factors such as temperature, pressure, and humidity along the propagation path contribute to slant path attenuation. Thus, the effective path length varies from location to location, months of the year, the height of the station above the sea level, and elevation angle. In order to estimate for the attenuation, the following parameters are pre-requisite, viz: Frequency, f (GHz), Pressure, p (hPa), Air temperature, T (°C), Water vapor density, ρ (g/m^3)

The total gaseous attenuation (dB) is computed using equation (1) (ITU-R, 2013):

$$A_G = \sum_{n=1}^{k} a_n \gamma_n \tag{1}$$

where γ_n is the specific attenuation of the n^{th} layer, while k is the total number of the layers, A_G The specific attenuation, γ_n, (dB/km), is given as:

$$N_O^{''}(f) = \sum_{io} S_i F_i + N_D^{''}(f) \tag{3}$$

$$N_W^{''}(f) = \sum_{io} S_i F_i \tag{4}$$

where S_i stands for strength of the i-th oxygen or water vapor line, F_i represents the oxygen or water vapour line shape factor, and $N_D^{''}(f)$ denotes the dry continuum due to pressure-induced nitrogen absorption and also the Debye spectrum. These are further expressed as:

$$S_i = a_1 \times 10^{-7} \text{p } \theta^3 \exp\,[a_2(1-\theta)] \quad \text{for oxygen} \tag{5}$$

$$S_i = b_1 \times 10^{-1} \text{e } \theta^{3.5} \exp\,[b_2(1-\theta) \quad \text{for water vapor} \tag{6}$$

$$N_D^{''}(f) = \text{f p } \theta^2 \left[\frac{6.14 \times 10^{-5}}{d\left[1+\left(\frac{f}{d}\right)^2\right]} + \frac{1.4 \times 10^{-12} p \theta^{1.5}}{1+1.9 \times 10^{-5} f^{1.5}}\right] \tag{7}$$

where p, e, θ, and d are dry air pressure (hPa), water vapour partial pressure (hPa), equivalent to 300/T, and the width parameter for the Debye spectrum respectively, while T is the temperature (K), e d, F_i are further expressed as:

$$\text{d} = 5.6 \times 10^{-4} \text{ (p + e) } \theta^{0.8} \tag{8}$$

$$\text{e} = \frac{pT}{216.7} \tag{9}$$

$$F_i = \frac{f}{f_i}\left[\frac{\Delta f - \delta(f_i - f)}{(f_i - f)^2 + \Delta f^2} + \frac{\Delta f - \delta(f_i + f)}{(f_i + f)^2 + \Delta f^2}\right] \tag{10}$$

where f_i stands for the oxygen or water vapour line frequency and Δf is the width of the line and is given as:

$$\Delta f = a_3 \times 10^{-4} \,(p\, \theta^{(0.8-a_4)} + 1.1 e\theta) \quad \text{for oxygen} \tag{11}$$

$$\Delta f = b_3 \times 10^{-4} \,(p\theta^{(b_4)} + b_5 e \theta^{b_6} \quad \text{for water vapour} \tag{12}$$

where the line width Δf, is further defined as:

$$\Delta f = \sqrt{\Delta f^{\,2} + 2.25 \times 10^{-6}} \quad \text{for oxygen} \tag{13}$$

$$\Delta f = 0.535 \Delta f + \sqrt{\left(0.2217 \Delta f^{\,2} + \frac{2.1316 \times 10^{-12} f_i^2}{\theta}\right)} \quad \text{for water} \tag{14}$$

Also, δ is a corrections factor that arises due to the interference affects in oxygen lines, and given as;

$$\delta = (a_5 + a_6 \theta) \times 10^{-4} (p + e) \theta^{0.8} \quad \text{for oxygen} \tag{15}$$

$$\delta = 0 \quad \text{for water vapour} \tag{16}$$

The parameters for $a_1, a_2, a_3, a_4, a_5, a_6$ and $b_1, b_2, b_3, b_4, b_5, b_6$ are spectroscopic data for oxygen and water vapor attenuation respectively given in (ITU-R, 2013).

Results and Discussion

Prediction of gaseous attenuation in selected locations in Nigeria involves the collection of five years radiosonde climatic parameters which are: temperature, relative humidity and pressure values from Nigeria Meteorological Agencies (NIMET) for proper analysis. It is worthy of note that, radiosonde soundings do not address climatic parameters at definite heights. Radiosonde balloons are launched two times per day at around 10 am in the morning and 11 pm in the night. In some isolated conditions, data is reported three times daily.

Prediction of Atmospheric Gaseous Attenuation

Water vapor, oxygen and smog absorb radio frequency energy as radio signals are propagated in the atmosphere. Absorption due to gaseous attenuation on the operational frequencies are caused by the impact of the tropospheric components. Results of gaseous attenuation at different heights of the six-geopolitical zones of Nigeria at the window range of (1 to 1000 GHz) frequencies using equation 2 are shown in figures 1 to 6.

The figures show a similar pattern over the selected height throughout the six geopolitical zones, but with different values. It is observed in figure 1 that, as the frequency increases, the attenuation values of water vapor and oxygen increase. The lowest height depicting height at the ground level for each of the study location.

Additionally, attenuation experienced sudden increase at exactly 60 GHz frequency due to the resonance effect for both water vapor density and oxygen. It is equally observed that, for water vapor density component, attenuation experiences resonance effect for the various heights (i. e 0.5 0.5 km, 1 km, 2 km, 5 km and 10 km) at frequencies 190 GHz, 320 GHz, 390 GHz, 450 GHz, 550 GHz and 620 GHz respectively. This indicates that, irrespective of height of the radiating and receiving antenna of link above the sea level, the same effect of gaseous attenuation is experienced when signal is propagated at the stated frequencies.

Furthermore, gaseous attenuation experience resonance at (0.5 km, 1 km 2 km, 5 km and 10 km) heights when the propagated signal is at 110 GHz, 370 GHz, 430 GHz, 490 GHz and 760 GHz respectively. These frequency bands correspond to resonances of water vapor and dry air respectively, and are not employed for downlinks and uplinks. Hence, satellites direct links may utilize the absorptive bands by bypassing the atmosphere.

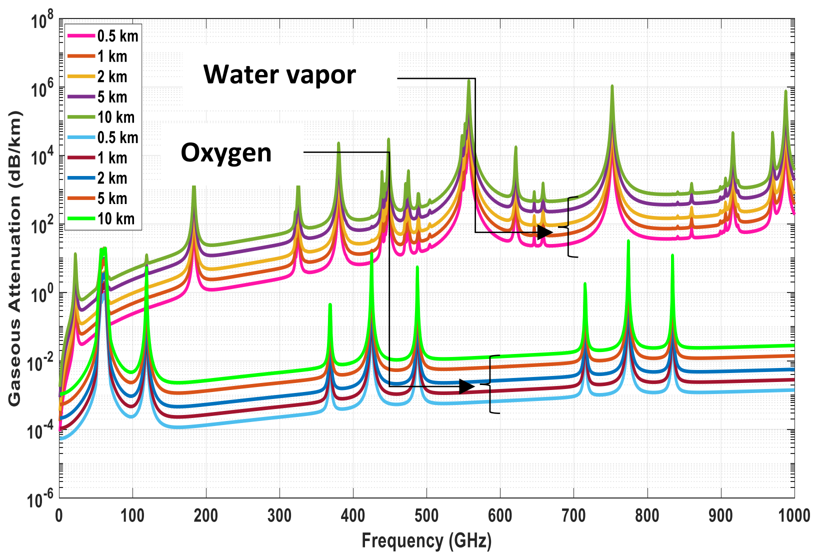

Figure 2. Gaseous attenuation in Abuja (North Central) at deferent heights

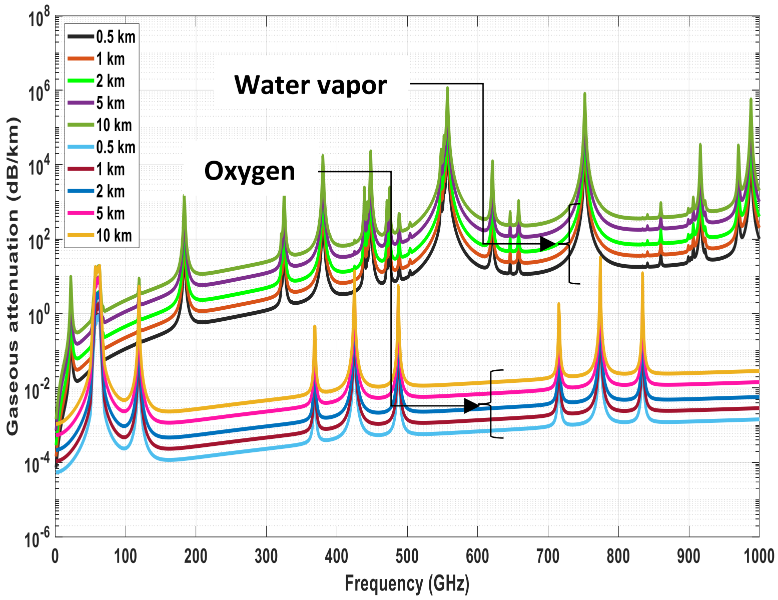

Figure 3. Gaseous attenuation in Bauchi (North East) at deferent heights

Figure 2 depicts a maximum value of attenuation due to water vapor components at 560 GHz frequency. Result further shows that, at 75 GHz and 120 GHz frequencies, resonance occurred for both the oxygen and water vapor. This indicates that, absorption became very high at those frequencies.

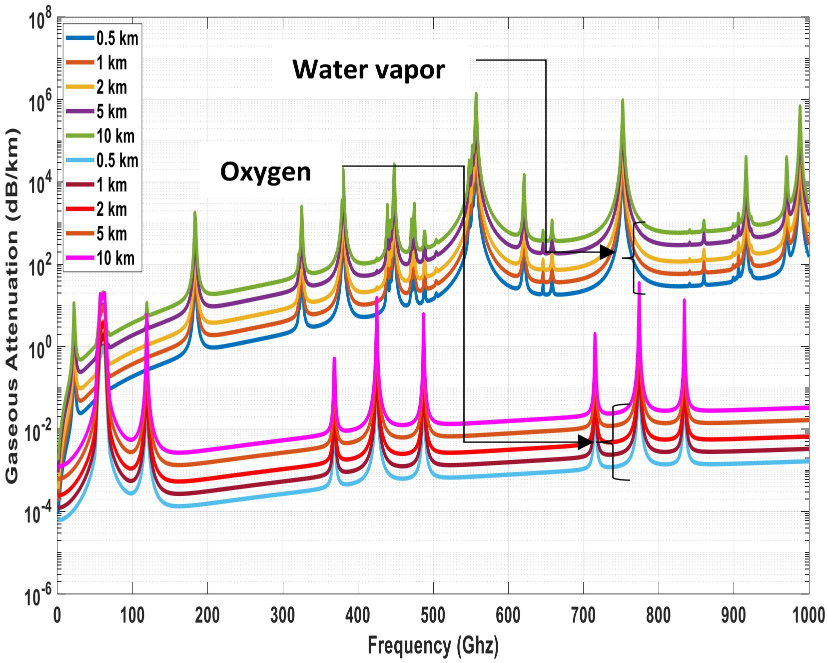

Figure 4. Gaseous attenuation in Lagos (South West) at deferent heights.

It is worth to note that, as the frequencies increases, the corresponding values of attenuation increases. Absorption and scattering of signals usually happen at higher frequencies as compared to the lower the lower frequencies range. It could be observed that, the values for oxygen attenuation do not change readily throughout the range of frequencies considered.

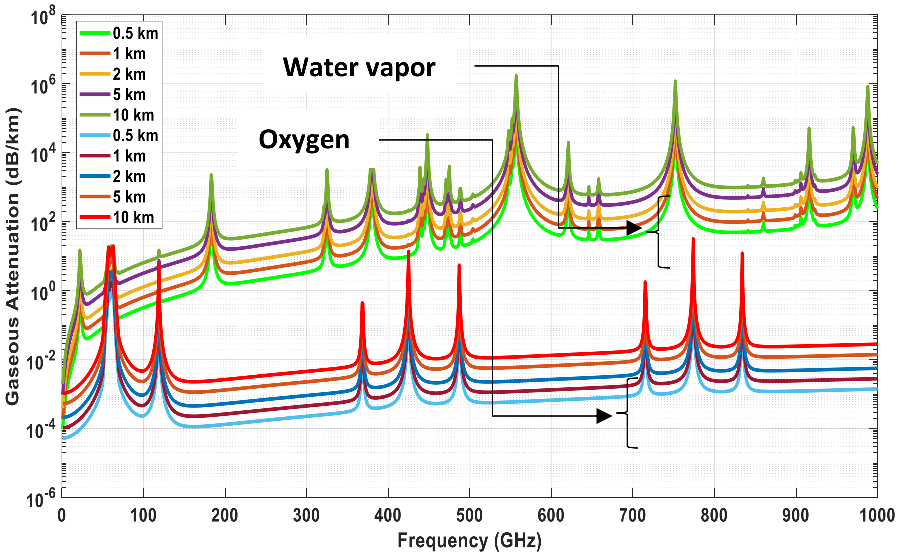

Figure 5. Gaseous attenuation in Portharcourt (South South) at deferent heights

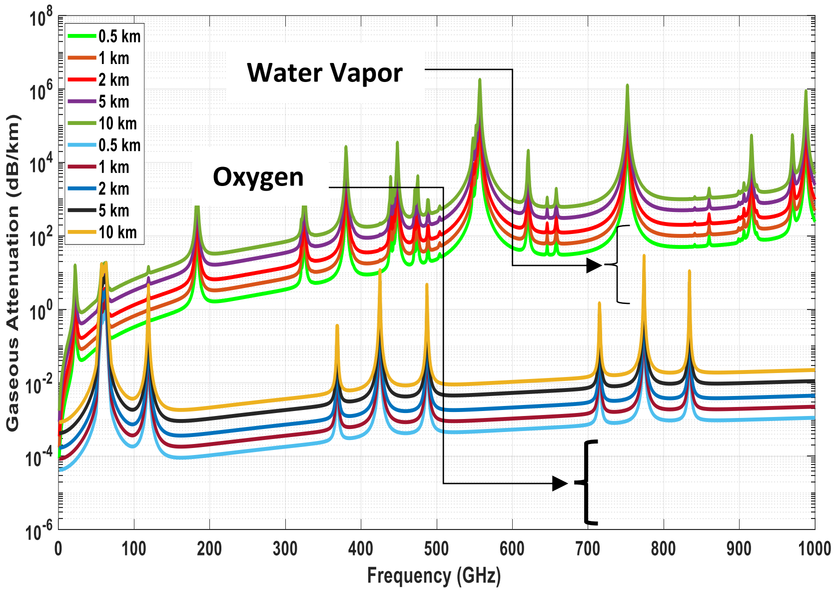

Figure 6. Gaseous attenuation in Enugu (South East) at deferent heights

Water vapor density values were obtained with the use of equation 9. It is observed in figure 7 that, highest values of temperature values were obtained in February, March and May.

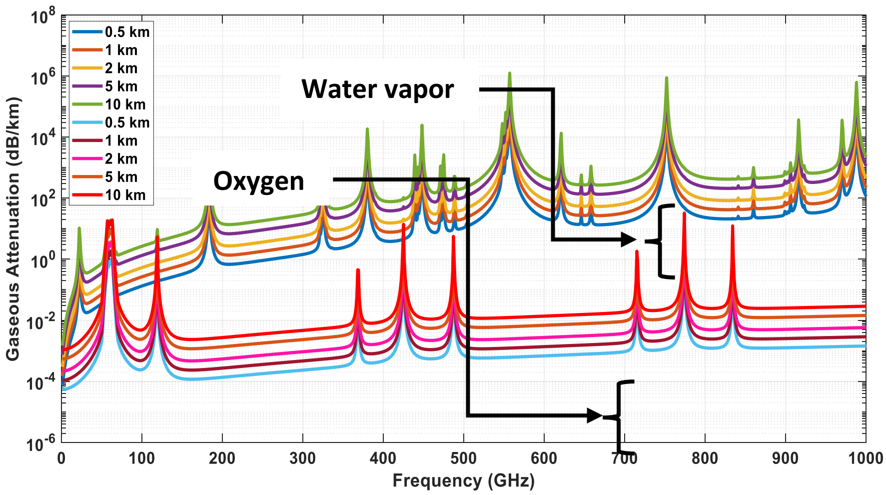

Figure 7. Gaseous attenuation in Kaduna (North West) at deferent heights

Therefore, a minimum attenuation values would be experienced by the signal. However, with reduced values of temperature obtained in the month of July to October, corresponding values of attenuation would be maximum due to temperature component. Consequently, with an increase in pressure, the value of attenuation increases proportionately. Tables 1 to 6 shows the monthly variation values of attenuation due to water vapor and oxygen for the various frequency bands (i.e. L band, UHF band, S band, C band, X band, Ku band, K band and Ka band) across the six geopolitical zones of Nigeria. It is evidenced that gaseous attenuation in the troposphere varies annually for each of the frequency band throughout the year. In addition to seasonal variability, the gaseous attenuation varies with frequency bands. However, in this research, tables 1 to 6 show that absorption of the propagated signal is also caused by water vapor and oxygen at different bands of frequency of propagation. In table 1, gaseous attenuation followed the same trend for L, UHF, S, and C bands respectively throughout the year. However, there is a slight increase in the attenuation for K and Ka bands. The effect is due to increase in the value of frequency.

Table 1.Gaseous attenuation at different frequency bands for Port Harcourt (South South)

Months/Bands /Attenuation		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
L Band	Water Vapor (*1e-3)	0.30	0.40	0.400	0.400	0.400	0.400	0.400	0.500	0.400	0.400	0.400	0.400
	Oxygen (*1e-03)	0.09	0.08	0.08	0.09	0.10	0.13	0.14	0.14	0.14	0.11	0.10	0.09
UHF Band	Water Vapor (*1e-3)	0.50	0.80	0.800	0.700	0.800	0.800	0.800	0.900	0.800	0.700	0.700	0.700
	Oxygen (*1e-03)	0.09	0.08	0.08	0.09	0.10	0.13	0.14	0.14	0.14	0.11	0.10	0.09
S Band	Water Vapor (*1e-3)	0.90	1.30	0.130	1.20	4.10	1.40	1.30	1.50	1.30	1.10	1.10	1.20
	Oxygen (*1e-03)	0.09	0.08	0.08	0.09	0.10	0.13	0.14	0.14	0.14	0.12	0.10	0.10
C band	Water Vapor (*1e-3)	3.20	5.20	5.20	4.70	5.40	5.20	4.80	5.50	4.80	4.20	4.30	4.50
	Oxygen (*1e-03)	0.10	0.08	0.09	0.09	0.11	0.14	0.15	0.15	0.15	0.12	0.10	0.10
X Band	Water Vapor (*1e-3)	7.80	12.70	12.60	11.40	13.40	12.50	11.70	13.40	11.70	10.20	10.40	11.00
	Oxygen (*1e-03)	0.11	0.09	0.09	0.10	0.12	0.15	0.16	0.17	0.16	0.14	0.11	0.11
Ku Band	Water Vapor (*1e-3)	33.60	53.10	52.70	48.20	55.80	53.40	50.00	57.70	50.20	43.50	44.00	46.80
	Oxygen (*1e-03)	0.13	0.11	0.12	0.13	0.15	0.19	0.21	0.21	0.20	0.17	0.14	0.14
K Band	Water Vapor (*1e-3)	80.60	126.70	125.70	115.2	133.20	127.70	120.20	137.50	120.00	104.00	105.70	111.90
	Oxygen (*1e-02)	0.20	0.17	0.18	0.19	0.23	0.28	0.31	0.32	0.31	0.26	0.22	0.21
Ka Band	Water Vapor (*1e-3)	74.20	122.00	120.30	109.40	125.70	118.80	110.20	126.90	110.00	96.00	88.00	105.40
	Oxygen (*1e-03)	0.64	0.53	0.56	0.61	0.71	0.89	0.98	1.00	0.97	0.80	0.68	0.67

Table 2: Gaseous attenuation at different frequency bands for Enugu (South East)

Months/Bands /Attenuation		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
L Band	Water Vapor (*1e-3)	0.30	0.40	0.40	0.40	0.40	0.50	0.50	0.50	0.50	0.40	0.30	0.30
	Oxygen (*1e-03)	0.07	0.06	0.06	0.07	0.08	0.10	0.11	0.11	0.12	0.08	0.07	0.09

UHF Band	Water Vapor (*1e-3)	0.50	0.70	0.80	0.80	0.90	0.90	0.90	0.90	0.90	0.80	0.50	0.50
	Oxygen (*1e-03)	0.07	0.06	0.06	0.07	0.08	0.10	0.12	0.11	0.12	0.09	0.07	0.09
S Band	Water Vapor (*1e-3)	0.80	1.20	1.40	1.40	1.40	1.50	1.50	1.50	1.50	1.30	0.80	0.80
	Oxygen (*1e-03)	0.07	0.06	0.06	0.07	0.08	0.10	0.12	0.12	0.13	0.09	0.07	0.09
C band	Water Vapor (*1e3)	3.20	4.90	5.40	5.60	5.70	5.80	5.90	5.70	6.00	5.00	0.80	0.80
	Oxygen (*1e-03)	0.08	0.07	0.06	0.07	0.09	0.11	0.12	0.12	0.13	0.09	0.08	0.09
X Band	Water Vapor (*1e3)	7.80	12.00	13.20	13.70	13.80	14.10	14.20	13.80	14.50	12.30	2.90	3.00
	Oxygen (*1e-03)	0.08	0.07	0.07	0.08	0.09	0.12	0.14	0.14	0.15	0.10	0.09	0.10
Ku Band	Water Vapor (*1e-3)	34.3	50.80	55.20	57.50	58.10	59.70	60.70	58.90	62.20	52.00	31.10	32.40
	Oxygen (*1e-03)	0.10	0.09	0.09	0.10	0.12	0.15	0.17	0.17	0.18	0.13	0.11	0.13
K Band	Water Vapor (*1e-3)	82.23	121.50	131.60	137.20	138.60	142.60	144.90	140.07	148.70	124.30	74.80	77.90
	Oxygen (*1e-03)	0.16	0.14	0.13	0.15	0.18	0.22	0.26	0.26	0.28	0.19	0.16	0.19
Ka Band	Water Vapor (*1e-3)	74.00	115.10	126.90	132.00	132.10	134.70	135.60	131.60	137.70	117.00	66.90	68.80
	Oxygen (*1e-03)	0.50	0.44	0.41	0.48	0.56	0.72	0.81	0.81	0.88	0.60	0.51	0.61

It is evidenced that both the Lagos (South West, Abuja (North Central), Enugu (South East) and Portharcourt (South South) have the highest values of water vapor attenuation at K and Ka Bands in months January through to September. The reason is traceable to the nearness of those locations to the ocean. Oxygen attenuation in those areas is not as high as that of the water vapor.

Table 3. Gaseous attenuation at different frequency bands for Lagos (South West)

Months/Bands /Attenuation		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
L Band	Water Vapor (*1e-3)	0.20	0.30	0.03	0.30	0.30	0.40	0.40	0.40	0.40	0.30	0.30	0.20
	Oxygen (*1e-03)	0.07	0.10	0.10	0.12	200.00	200.00	200.00	200.00	200.00	128.10	114.00	73.60
UHF Band	Water Vapor (*1e-3)	0.40	0.50	0.50	0.50	0.60	0.60	0.70	0.60	0.60	0.60	0.50	0.20
	Oxygen (*1e-03)	72.80	104.40	104.20	119.70	134.30	0.20	0.20	0.20	0.20	129.00	114.9	74.10
S Band	Water Vapor (*1e-3)	0.70	0.70	0.70	0.70	0.90	1.00	1.10	0.90	1.00	0.90	0.80	0.40
	Oxygen (*1e-03)	0.07	0.11	0.11	0.12	0.14	0.20	0.20	0.20	0.20	0.13	0.12	0.07
C band	Water Vapor (*1e-3)	2.50	2.70	2.70	2.70	3.40	3.40	3.70	3.20	3.50	3.20	3.00	1.30
	Oxygen (*1e-03)	0.08	0.11	0.11	0.13	0.14	0.20	0.20	0.20	0.20	0.14	0.12	0.08

X Band	Water Vapor (*1e-3)	6.10	6.50	6.40	6.40	8.10	8.20	9.00	7.60	8.40	7.80	7.20	3.00
	Oxygen (*1e-03)	0.09	0.12	0.12	0.14	0.16	0.20	0.20	0.20	0.20	0.15	0.14	0.09
Ku Band	Water Vapor (*1e-3)	25.60	28.10	27.90	28.10	35.30	36.00	39.70	33.60	36.70	33.80	30.90	12.90
	Oxygen (*1e-03)	0.11	0.15	0.15	0.18	0.20	0.20	0.20	0.20	0.20	0.19	0.17	0.11
K Band	Water Vapor (*1e-3)	61.20	67.50	66.90	67.40	84.70	86.40	95.20	80.70	87.90	80.90	74.10	30.90
	Oxygen (*1e-03)	0.16	0.23	0.23	0.27	0.30	0.30	0.40	0.40	0.30	0.29	0.26	0.17
Ka Band	Water Vapor (*1e-3)	57.90	61.30	60.70	60.30	76.00	77.00	84.30	70.90	78.50	73.20	67.60	28.10
	Oxygen (*1e-03)	0.51	0.73	0.74	0.85	0.95	0.11	0.13	0.12	0.11	0.91	0.81	0.53

Table 4. Gaseous attenuation at different frequency bands for Abuja (North Central)

Months/Bands /Attenuation		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
L Band	Water Vapor (*1e-3)	0.20	0.20	0.30	0.40	0.40	0.40	0.50	0.70	0.50	0.40	0.30	0.20
	Oxygen (*1e-03)	0.13	0.10	0.11	0.11	0.13	0.10	0.20	0.14	0.20	0.14	0.12	0.13
UHF Band	Water Vapor (*1e-3)	0.30	0.40	0.40	0.70	0.80	0.80	0.80	0.13	0.90	0.70	0.50	0.30
	Oxygen (*1e-03)	0.13	0.10	0.11	0.11	0.13	0.10	0.20	0.14	0.20	0.14	0.12	0.13
S Band	Water Vapor (*1e-3)	0.50	0.60	0.70	1.20	1.20	1.20	1.30	2.20	1.50	1.10	0.70	0.50
	Oxygen (*1e-03)	0.13	0.11	0.11	0.11	0.13	0.20	0.20	0.14	0.20	0.14	0.12	0.13
C band	Water Vapor (*1e-3)	1.60	2.30	2.60	4.60	4.70	4.60	4.70	8.60	5.50	3.50	2.50	1.70
	Oxygen (*1e-03)	0.14	0.11	0.11	0.12	0.14	0.20	0.20	0.15	0.20	0.15	0.13	0.14
X Band	Water Vapor (*1e-3)	3.90	5.60	6.30	11.10	11.40	11.10	11.40	21.10	13.30	9.50	6.10	4.10
	Oxygen (*1e-03)	0.15	0.12	0.13	0.13	0.16	0.20	0.20	0.17	0.20	0.17	0.14	0.16
Ku Band	Water Vapor (*1e-3)	18.30	25.80	28.80	48.70	49.40	48.40	49.80	90.30	57.70	41.80	27.50	19.40
	Oxygen (*1e-03)	0.19	0.15	0.16	0.16	0.19	0.20	0.20	0.21	0.20	0.21	0.18	0.19
K Band	Water Vapor (*1e-3)	44.30	62.40	69.50	116.70	118.40	116.00	119.40	215.50	138.10	100.40	66.30	47.00
	Oxygen (*1e-03)	0.28	0.23	0.24	0.24	0.29	0.30	0.40	0.32	0.30	0.31	0.27	0.29
Ka Band	Water Vapor (*1e-3)	35.40	51.50	58.20	104.60	107.30	104.10	107.00	199.60	125.20	89.40	56.30	36.90
	Oxygen (*1e-03)	0.89	0.73	0.74	0.77	0.92	0.11	0.11	0.99	011	0.99	0.84	0.92

Table 5. Gaseous attenuation at different frequency bands for Kaduna (North West)

Months/Bands /Attenuation		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
L Band	Water Vapor (*1e-3)	0.20	0.10	0.10	0.20	0.30	0.30	0.40	0.50	0.40	0.30	0.20	0.10
	Oxygen (*1e-03)	0.10	0.09	0.09	0.08	0.09	0.02	0.13	0.13	0.12	0.11	0.10	0.10
UHF Band	Water Vapor (*1e-3)	0.20	0.10	0.20	0.40	060	0.50	0.60	0.80	0.80	0.50	0.20	0.20
	Oxygen (*1e-03)	0.10	0.09	0.09	0.08	0.09	0.12	0.13	0.13	0.13	0.11	0.10	0.10
S Band	Water Vapor (*1e-3)	0.20	0.20	0.30	0.70	0.90	0.80	1.00	1.40	1.30	0.80	0.30	0.20
	Oxygen (*1e-03)	0.10	0.09	0.09	0.08	0.10	0.12	0.13	0.14	0.13	0.11	0.10	0.10
C band	Water Vapor (*1e-3)	0.50	0.50	0.90	2.50	3.50	3.00	3.80	5.10	4.80	2.90	1.00	0.50
	Oxygen (*1e-03)	0.20	0.10	0.10	0.09	0.10	0.13	0.14	0.14	0.14	0.12	0.11	0.11
X Band	Water Vapor (*1e-3)	1.10	1.10	2.20	6.10	8.60	7.20	9.30	12.50	11.70	7.00	2.40	1.10
	Oxygen (*1e-03)	0.20	0.11	0.11	0.09	0.11	0.14	0.16	0.16	0.15	0.13	0.12	0.12
Ku Band	Water Vapor (*1e-3)	5.50	5.50	10.90	27.10	37.50	31.80	40.60	53.90	50.90	31.10	11.20	5.60
	Oxygen (*1e-03)	0.20	0.13	0.14	0.12	0.14	0.17	0.20	0.20	0.19	0.16	0.15	0.15
K Band	Water Vapor (*1e-3)	13.30	13.50	26.50	65.30	90.00	76.40	97.30	129.00	122.00	74.90	27.20	13.70
	Oxygen (*1e-03)	0.30	0.20	0.21	0.18	0.21	0.26	0.30	0.30	0.29	0.24	0.23	0.22
Ka Band	Water Vapor (*1e-3)	91.0	92.00	19.50	57.70	81.50	67.80	87.40	118.20	110.50	65.90	21.00	9.50
	Oxygen (*1e-03)	1.00	0.63	0.65	0.56	0.66	0.83	093	0.94	0.92	0.76	0.73	0.71

Table 6. Gaseous attenuation at different frequency bands for Enugu (South East)

Months/Bands /Attenuation		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
L Band	Water Vapor (*1e-3)	0.20	0.20	0.10	0.10	0.10	0.30	0.30	0.40	0.40	0.20	0.20	0.20
	Oxygen (*1e-03)	0.20	0.11	0.09	0.05	0.07	0.12	0.12	0.22	0.12	0.10	0.12	0.20
UHF Band	Water Vapor (*1e-3)	0.30	0.20	0.20	0.20	0.30	0.50	0.40	0.60	0.60	0.40	0.30	0.30
	Oxygen (*1e-03)	0.20	0.11	0.10	0.05	0.07	0.13	0.12	0.12	0.12	0.11	0.12	0.20
S Band	Water Vapor (*1e-3)	0.30	0.30	0.20	0.40	0.50	0.70	0.60	1.00	1.00	0.60	0.40	0.40
	Oxygen (*1e-03)	0.20	0.11	0.10	0.05	0.07	0.13	0.12	0.12	0.11	0.12	0.20	0.20
C band	Water Vapor (*1e-3)	0.80	0.80	0.60	1.40	2.20	2.60	2.10	3.80	3.80	2.30	1.20	1.30
	Oxygen (*1e-03)	0.20	0.12	0.10	0.05	0.08	0.13	0.13	0.13	0.13	0.11	0.12	0.20
X Band	Water Vapor (*1e-3)	1.80	1.90	1.50	3.50	5.40	6.30	5.20	9.20	9.20	5.50	2.80	3.10
	Oxygen (*1e-03)	0.20	0.16	0.14	0.07	0.11	0.18	0.18	0.18	0.18	0.16	0.17	0.20

Ku Band	Water Vapor (*1e-3)	9.00	9.20	7.20	16.00	20.70	28.90	23.40	40.90	40.90	25.50	13.50	14.90
	Oxygen (*1e-03)	0.20	0.16	0.14	0.07	0.11	0.18	0.18	0.18	0.18	0.16	0.17	0.20
K Band	Water Vapor (*1e-3)	21.80	22.50	17.70	38.80	48.90	69.70	56.40	98.30	98.50	61.80	32.80	36.20
	Oxygen (*1e-03)	0.40	0.24	0.21	0.11	0.16	0.28	0.27	0.28	0.27	0.23	0.26	0.30
Ka Band	Water Vapor (*1e-3)	15.60	16.90	12.50	31.80	53.20	58.10	47.60	86.30	47.60	86.30	24.40	26.90
	Oxygen (*1e-03)	0.11	0.78	0.67	0.34	0.50	0.88	0.86	0.87	0.84	0.74	0.82	0.10

Conclusion

Tropospheric attenuation (attenuation due to gases) has been investigated. Results obtained from the predictions show that gaseous attenuation increase for frequencies above 60 GHz. This may be due to the effect of water vapor density and dry air on signals at the frequency of about 110 GHz, 190 GHz, 320 GHz, 370 GHz, 390 GHz, 430 GHz, 450 GHz, 490 GHz, 550 GHz, 620 GHz, and 760 GHz where atmospheric constituents reached its individual points of resonance and the absorption effects also became high. These imply that the parameters produced by troposphere have their significant effect on satellite up-link and down-link. Therefore, satellites direct links may utilize the absorptive bands by bypassing the atmosphere.

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