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Attenuation of Dust and Sand Storms of Microwave Signal at Sabha City

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ABSTRACT: *Dust and sand storms attenuation is one of the main problem in usage of microwave bands for terrestrial and DB satellite at desert areas. This paper present and enforce a mathematical version to are expecting the microwave sign attenuation because of dust and sand storm withinside city of Sabha. The foremost enter parameters for the version are visibility, sign frequency, the quantity of dust particular sand humidity. The offered version successfully predicts the microwave sign attenuation. The effects display that the attenuation will increase with frequencies and humidity and reduces with visibilities. The observe located out that the very best values of attenuation in sabha city varies from 0.13 to 9.78 dB/km at humidity 60%. The final results of this observe will facilitate the layout of dependable conversation structures through thinking about the attenuation traits because of atmospheric situations that may permit mitigation of channel fading circumstance through adaptively choosing suitable propagation parameters.*

KEYWORDS: *Attenuations, Dust and Sand Storm, Libya, Microwave, Communication.*

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I. INTRODUCTION

Different climate situations consisting of rain, snow, scintillation, humidity, sand and dust storms play sizable function in inflicting propagation impairments on DB satellite signals. These verity of impairments relies upon the severity of climate situations located. Dust and sand (DUSA) will reason attenuation, however an extreme DUSA may also cause satellite link unavailability. Rain and Snow attenuations are dominant in regions consisting of America, Europe, etc., while sand and dust storms are located in exclusive regions round the sector as in center east. So, the predominant attenuation contributing thing varies relying upon the nearby meteorological situations. Early researches had been targeted at the attenuation of the DUSA as a uniform distribution or took a particular geometric shape. This approximation gave suitable effects all through excessive or mild visibility; but it's going to now no longer offer the designers with decent effects at low visibility (Harb et al.,2012). Signal attenuation because of dust and sand storms had been certainly below investigation, in Sabha City for several decades. Sebha is the third largest city in Libya and is located in the southern part of Libya in the middle of the Sahara Desert (Fig.1).

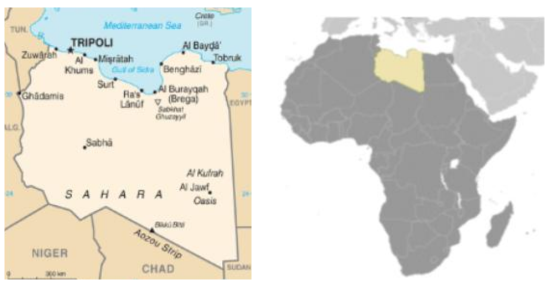

Fig.1: Map of Libya indicating the major sites, and the geographic location of Libya in the African continent

Dust storms are significant meteorological phenomenon that happens for a considerable percent of time withinside the Libya (Fig.2). Dust storms are among the most severe environmental problems in certain regions of the world. It has estimated that the Sahara Desert alone contributes 2×10^8 - 3.3×10^8 tons per year or between 40–66% of the total dust. Dust storms may be traced as far as 4000 km from their origin (Nassar et al., 2018). Economic impacts of dust storms, reported in the literature include reduced soil fertility and damage to crops, a reduction of solar radiation and in consequence the efficiency of solar devices (Nassar, 2006; Hafez, 2019), damage to telecommunications and mechanical systems, dirt, air pollution (Nassar et al., 2017). Recent years facts display that a phenomenon charge is growing because of the worldwide environmental. Wireless communique networks and microwave structures were set up withinside the southern a part of Libya, wherein there are dust and sand storms that can have an effect on the microwave signal propagation. When microwaves and millimeter waves pass through a medium containing precipitations like sand and dust particles, the signals get attenuated through absorption and scattering of energy out of beam through the sand and dust particles. The most important item of this paper is to figuring out the attenuation of the wireless microwave communication links situation to sand and dust storms on withinside the southern place of Libya (Sebha) through. The end result confirmed that there are a few issues that must be taken into consideration withinside the places of land communique stations.

1.1. Signal attenuation of The Dust Storm

Signal attenuation caused by dust storm is one of the major problems in utilization of microwave bands for terrestrial and space communication especially at desert and semi desert area. Dust storms occur in many parts of the world, especially in the African Sahara, Middle East and arid parts of Asia for a significant percentage of time. During the storm, dust particles raised high enough above the earth's surface to lie within the path of microwave radio links causing a loss of signal energy and resulting in service interruption (Nassar et al., 2021).

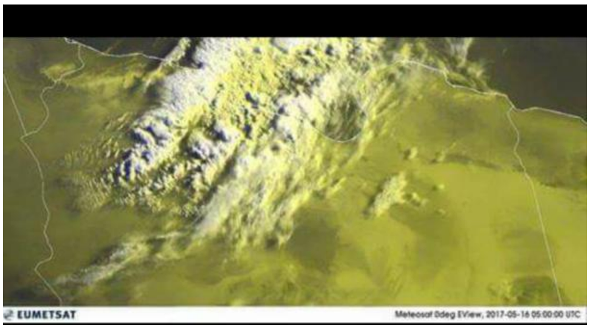

Fig.2: A satellite image of a sand storm coming from the southwest of Libya [source: EUMETSAT 16/05/2017 at 05:00:00 UTC]

Table.1: Listing of Dielectric Constants at Various Frequencies

Frequency GHz	Soil Type	ε'	ε''
1 – 3	Loam	3.5	0.14
3 - 10.5	clay, silt	5.73	0.474
10.5 – 14	Sand	3.9	0.62
14 – 24	Sad	3.8	0.65
24 – 37	Loam	2.88	0.3529

The depth of dust storm isn't uniformly dispensed and it varies each horizontally and vertically with the very best withinside the center and reducing across the horizontal start, end and vertical edges. It consists of numerous layers even as transferring from the base, in vertical direction, to the top. These layers constitute exceptional degrees of visibility primarily based totally on non-uniform particle length and depth distributions withinside the DUSA as proven in Fig.2. This discern presentations the dust storm for exceptional top layers and visibilities. Thus, the visibility will increase to its most at the very best stage of dust storm. The consequences had been obtained for up to two km in dust storms altitude at the side of exceptional envisioned visibilities. Such as, for 1.82km of visibility, the height can be equal to 1.198 km. The physical representation of dust storm in step with visibility versions with exceptional degrees shall cause an progressed estimation of climate attenuation (Abuhamoud, 2014).

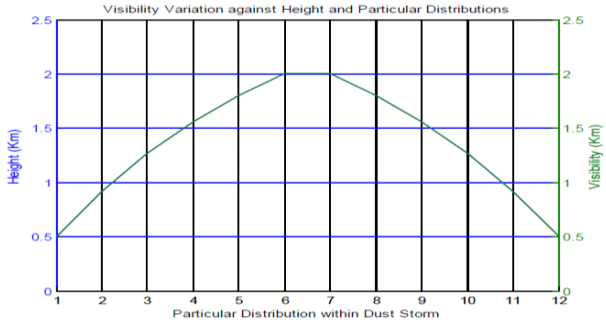

Fig.3: Visibility variation of dust storm

Therefore, the particles radii decrease as the height increases according to a vertical dust particles size distribution, hence the visibility will increase with the height the attenuation which constitute lesser attenuation (Alhuwaimel, 2012). Note that, the line at the center of the figure divides the dust storm into two similar phase0s. Therefore, accurate estimation of dust storm height leads to better estimation of the channel attenuation which in turn, saves extra transmission power and improves QoS. These storms present the major cause of attenuation on satellite communication channels (Abuhamoud, 2014)

1.2. Scattering of Single-Particle

Signals suffer absorption and scattering by the atmosphere especially at higher frequencies where the scattering effects become more severe. The knowledge of these scattering characteristics is essential to design reliable communications (Fadil, Abuhamoud, 2016). The basic theory underling mathematical model for attenuation is the theory for single particle scattering. The propagation effects may be modeled by volumetric integration of scattering by individual particles. When an object is illuminated by a wave, a part of the incident power is scattered out and another part is absorbed by the object. The characteristics of these two phenomena, scattering and absorption, can be expressed most conveniently by assuming an incident plane wave (Islam, et al., 2010).

1.3. Attenuation of Dust storm

The strategies of predicting the sign attenuation because of rain consequences may be implemented for dirt typhoon due to the fact the overall version for scattering in sand and dust particle populations is largely similar to that for a populace of hydrometeors; each of them are discrete random medium. The signal attenuation because of dust storm is expected typically with the aid of using fixing the ahead scattering amplitude function of a single particle. The solution can be completed the usage of the Rayleigh approximation or Mie solutions.
The method depends largely on the particle number and particle radius. The attenuation of electromagnetic radiation (AT) over a path of extent L through precipitating particles may be written as (Fadil, Abuhamoud, 2020):

$$A_T(\text{dB}) = \int_0^L A_p(\text{dx}) \qquad (1)$$

Where Ap (dB/km) is the specific attenuation characterizing the precipitating particles. The following expression is used to calculate the attenuation due to rain (Fadil, Abuhamoud, 2020):

$$A_p = 4.343 \times 10^3 \int_{a_{min}}^{a_{max}} \sigma_t(a).\,N(a)da[\text{dB/km}] \qquad (2)$$

Where N(a)da are particles number per unit volume of air with particles radius between r and r+dr, σt is the total attenuation cross section efficiency factors of particle of radius.

1.4. The Visibility

Calculating the attenuation by Eqs. (1,2) requires data for the number of particles of dust N, which is difficult to measure accurately. On the other hand, statistical information on dust-storm visibility is available. The expresses the visibility in terms of the particle density as (Goldhirsh, 2001):

$$V(km) = \frac{5.5\times10^{-4}}{Na_e{}^2} \qquad (3)$$

Where the units of N are particles/m^3 and a_e is the equivalent particle radius in meters. By solving N in the Eq. (3) we can express the particle density in terms of the visibility and the radius as (Islam et al., 2010):

$$N = \frac{5.5\times10^{-4}}{Va_e^2} \qquad (4)$$

II. METHODOLOGY

2.1. Analytical Models for Scattering

There are more than one models give an analytical solution for the scattering of a plane wave by a spherical particle, Rayleigh approximation and Mie solution. Rayleigh approximation loses its reliability as the size of the dust particles approaches the operating wavelength or vice-versa, because Rayleigh formula is based on the assumption that $a \ll \lambda$, where a is the dust particle radius and λ is the operating wavelength in meters. This is the reason why it is not used for predicting attenuations for frequencies higher than 37 GHz.

In contrast to Rayleigh scattering model, Mie solutions embrace all possible ratios of diameter to wavelength and do not depend upon any such limitation and can be utilized to predict attenuation in microwave band with high reliability especially at higher frequencies. The formula developed to predict signal attenuation caused by dust particles using Rayleigh approximation, so a new formula can predict signal attenuation due to dust particles at higher frequencies and it is highly recommended for new telecommunication application. The expression of the total cross-section efficiency factors (σ_t) using Mie solutions as (Goldhirsh, 2001):

$$\sigma_t = \frac{\lambda^2}{2\pi}(ka)^3(c_1 + c_2(ka)^2 + c_3(ka)^3) \quad (5)$$

Where C_1, C_2 and C_3 are constants whose values depend on real (ε') and imaginary part (ε'') of the dielectric constant of the permittivity of materials at microwave frequencies the particles as (Goldhirsh, 2001):

$$C_1 = \frac{6\,\varepsilon''}{(\varepsilon+2)^2 + \varepsilon''^2} \quad (6)$$

$$C_2 = \varepsilon' \left\{ \frac{6\times 7\varepsilon'^2 + 7\varepsilon'^2 + 4\varepsilon' - 20}{5[(\varepsilon'+2)^2 + \varepsilon'^2]^2} + \frac{1}{15} + \frac{5}{3[(2\varepsilon'+3)^2 + 4\varepsilon'^2]} \right\} \quad (7)$$

$$C_3 = \frac{4}{3}\left\{ \frac{(\varepsilon'-1)^2(\varepsilon'+2) + [2(\varepsilon'-1)(\varepsilon'+2) - 9] + \varepsilon'^4}{[(\varepsilon'+2)^2 + \varepsilon'^2]^2} \right\} \quad (8)$$

The complex permittivity depends on moisture contents in samples, the following empirical relation, as expressed in Eq. 9 and 10, estimate the variation of complex permittivity with relative humidity (Fadil, Abuhamoud, 2020):

$$\varepsilon' H = \varepsilon' + 0.04H - 7.78 \times 10^{-4} H^2 + 5.56 \times 10^{-6} H^3 \quad (9)$$

$$\varepsilon'' H = \varepsilon'' + 0.02H - 3.71 \times 10^{-4} H^2 + 2.76 \times 10^{-6} H^3 \quad (10)$$

where $\varepsilon', \varepsilon''$ is the dry dust dielectric constant and His the air relative humidity (percentage).

2.2. Sand and dust storm attenuation modelling

Sand and dust storm attenuation is implemented utilizing Eq. (17) as shown in Fig. 3 where sand particle average of the diameters radius considered equal to 50µm. Sand particle diameters, visibility and frequency represent the input for this model.

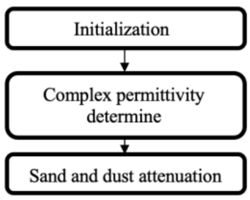

Fig. 4: Sand and dust storm attenuation model

By substituting Collin expression Eq. (5) for the total cross-section efficiency factors (σt) and the particle density expression in Eq. (4), A_d (dB/km) may alternately be expressed as in Eq. (11) as following (Goldhirsh, 2001):

$$A_d = \int_{a_{min}}^{a_{max}} [\frac{\lambda^2}{2\pi}(ka)^3(c_1 + c_2(ka)^2 + c_3(ka)^3).\frac{5.5\times10^{-4}}{Va_e^2}]da \quad (11)$$

A further approximation can be made in these calculations, assuming that every dust particle in a real storm may be replaced by an equivalent particle (a_e) whose radius is the mean radius for all dust particles. By this assumption the value of equivalent particle radius (a_e) is considered as constant value and Eq. (11) may alternately be expressed as algebraic expression in Eq. (12):

$$A_d = 4343 \times [\frac{\lambda^2}{2\pi}(ka)^3(c_1 + c_2(ka)^2 + c_3(ka)^3).\frac{5.5\times10^{-4}}{Va_e^2}] \quad (12)$$

By substituting k = 2π / λ in Eq. (12), we can express A_d by:

$$A_d = 4343 \times [\frac{\lambda^2}{2\pi}\left(\frac{2\pi a}{\lambda}\right)^3\left(c_1 + c_2\left(\frac{2\pi a}{\lambda}\right)^2 + c_3\left(\frac{2\pi a}{\lambda}\right)^3\right).\frac{5.5\times10^{-4}}{Va_e^2}] \quad (13)$$

By substituting Eq. (6,7 and 8) in Eq. (13) and after several algebraic calculations, we can alternately express the specific attenuation due to dust-storm A_d (dB/km) as:

$$A_d = \frac{a_e f}{V}(x + y{a_e}^2 f^2 + z a_e^3 f^3) \qquad [\,dB/km] \qquad (14)$$

Where a_e is the equivalent particle radius in meters, V is the visibility in km and f is the frequency in GHz and x, y and z are constants whose values depend on real (ε') and imaginary part (ε'') of the dielectric constant of the particles as:

$$x = \frac{1886.\varepsilon''}{(\varepsilon'+2)^2+\varepsilon'^2} \qquad (15)$$

$$y = 137 \times 10^3.\varepsilon' \left\{\frac{6\times7\varepsilon'^2+7\varepsilon'^2+4\varepsilon'-20}{5[(\varepsilon'+2)^2+\varepsilon'^2]^2} + \frac{1}{15} + \frac{5}{3[(2\varepsilon'+3)^2+4\varepsilon'^2]}\right\} \qquad (16)$$

$$z = 379 \times 10^4 \left\{\frac{(\varepsilon'-1)^2(\varepsilon'+2)+[2(\varepsilon'-1)(\varepsilon'+2)-9]+\varepsilon'^4}{[(\varepsilon'+2)^2+\varepsilon'^2]^2}\right\} \qquad (17)$$

Table.2: Listing of Dielectric Constants at Various Frequencies

Frequency GHz	Soil Type	ε'	ε''
1 – 3	Loam	3.5	0.14
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24 – 37	Loam	2.88	0.3529

III. RESULT AND DISCUSSION

City of Sabha turned into selected because the observe area for measuring the effect of dust and/or sand storms at the microwaves communication systems including DB satellite links, due to the fact the City has a desert weather and rapid wind full of dust from time to time. Climate statistics for the City of study, turned into obtained from climate station, we refer to the Libyan centre of metrology for getting the metrological data of the web page selected.

The results show that the attenuation increases with frequency and decreasing the visibility. The highest values of the attenuation for sand and dust storms are in Sebha this is because the sand storms is most severe in city, heavy dust storms reduce the visibility during the storms to few meters that reached (4 m). Dust and storms are not encountered frequently in the west and east regions.

In Table 3 the minimum value of the visibility about 4m,the highest average percentage of humidity was recorded from 20 to 51% and the maximum rate of humidity was recorded about 60%.The average complex permittivity of the samples collected in the studied city is equal to 6.3485 and 0.0929 respectively, the particle diameters generally vary from 1 µm to100 µm.

Table.3: Show the used parameters to calculate the attenuation.

<table>
<tr><th>The parameter</th><th colspan="3">The Value</th></tr>
<tr><td>Humidity (H)</td><td colspan="3">20 to 60%</td></tr>
<tr><td rowspan="4">Average complex permittivity</td><td>Band</td><td>Dry Media</td><td>Humid Media</td></tr>
<tr><td>S</td><td>4.56 +j0.251</td><td>5.63 + j0.90</td></tr>
<tr><td>X</td><td>5.73 +j0.415</td><td>6.8 + j1.054</td></tr>
<tr><td>Ku</td><td>5.50 +j1.300</td><td>6.57 + j 1.94</td></tr>
<tr><td>Particle diameters</td><td colspan="3">1 µm to100 µm</td></tr>
<tr><td>Visibility</td><td colspan="3">4 to 120 m</td></tr>
</table>

To expect the particular attenuation added through dust and sand storm the use of A mathematical model over microwave links in City of Sabha become applied in MATLAB. This model is perfect with all viable ratios of dust and sand particles diameter to wavelength and expect attenuation in microwave wave band with excessive reliability. In this model, the term visibility (V) is carried out to indicate the degree of dust storm density instate of overall range of dust debris (N). The model expressed the wireless channel attenuation as a function of that the microwave signal attenuation because of dust storm relies upon on visibility, frequency, dust particle radius, dielectric steady and humidity. The results withinside the tables beneath confirmed that the attenuation of microwave signal, for sand particle common value of the diameters radius same to 50µm and visibility among four to 120m, will increase with frequencies and humidity and reduces with visibilities.

The attenuation varies from 0.0045 to 0.66 dB/km at C-band and X-band frequencies when the humidity is equal to 0 %. While at humidity 60%, the attenuation varies from 0.023 to 3.93 dB/km. For Ku-band frequencies, the attenuation varies from 0.05 to 0.66 dB/km with a humidity equal to 0%, and from 0.13 to 9.78 dB/km at humidity 60%.

Table.4: Variation of sand attenuation (humidity 0 %)

Frequency (GHz)	Signal Attenuation (dB/km) at humidity 0 % ,with visibility			
	4m	10m	40m	120m
4	0.136	0.054	0.0135	0.004
8	0.336	0.134	0.033	0.011
12	0.663	0.265	0.665	0.022
18	1.529	0.612	0.153	0.052

Table.5: Variation of sand attenuation (humidity 20%)

Frequency (GHz)	Signal Attenuation (dB/km) at humidity 20 % ,with visibility			
	4m	10m	40m	120m
4	0.485	0.194	0.048	0.016
8	1.256	0.502	0.126	0.042
12	2.598	1.039	0.259	0.087
18	6.32	2.524	0.631	0.210

Table.6: Variation of sand attenuation (humidity 40%)

Frequency (GHz)	Signal Attenuation (dB/km) at humidity 40 % ,with visibility			
	4m	10m	40m	120m
4	0.609	0.244	0.061	0.020
8	1.609	0.643	0.161	0.054
12	3.379	1.352	0.388	0.113
18	8.34	3.335	0.834	0.278

Table.7: Variation of sand attenuation (dB/km) for frequency, visibility (humidity 60 %)

Frequency (GHz)	Signal Attenuation (dB/km) at humidity 60 % ,with visibility			
	4m	10m	40m	120m
4	0.698	0.558	0.138	0.046
8	1.856	0.742	0.185	0.062
12	3.935	1.574	0.394	0.131
18	9.785	3.915	0.978	0.326

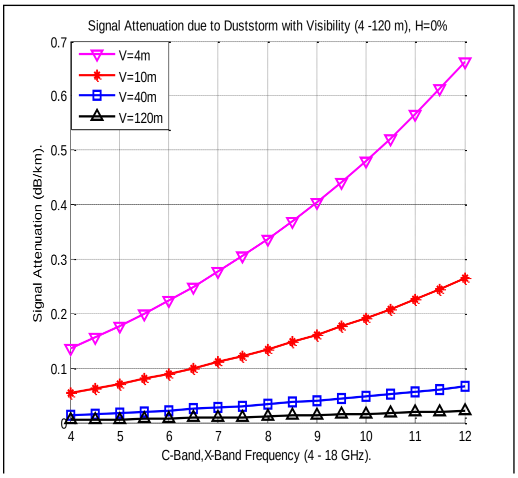

Fig.5: Signal attenuation (dB/km) Vs frequency at C-band and X-bandfor humidity 0%.

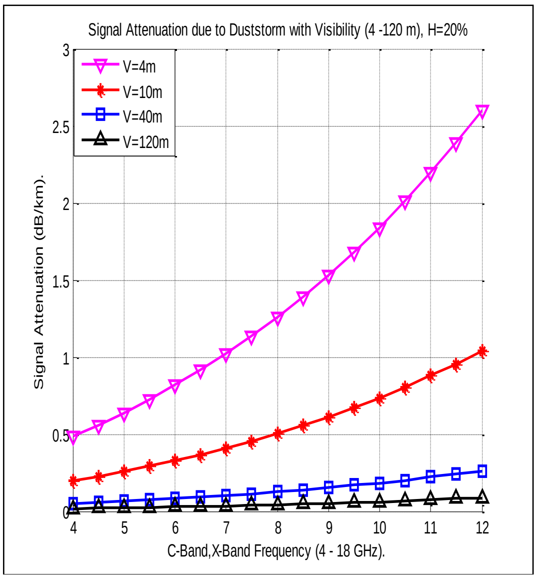

Fig.6: Signal attenuation (humidity 20%)

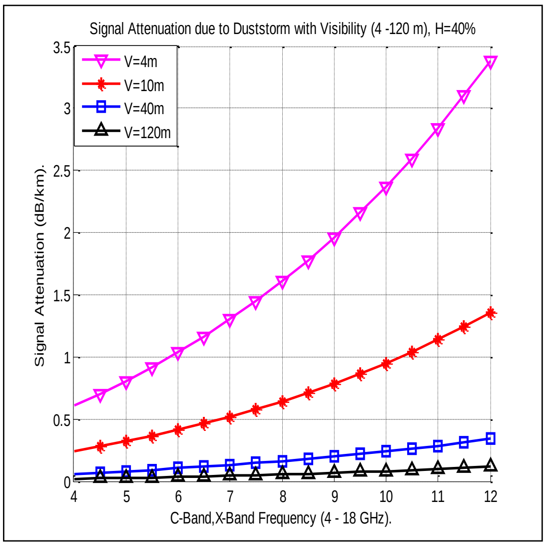

Fig.7: Signal attenuation (humidity 40%)

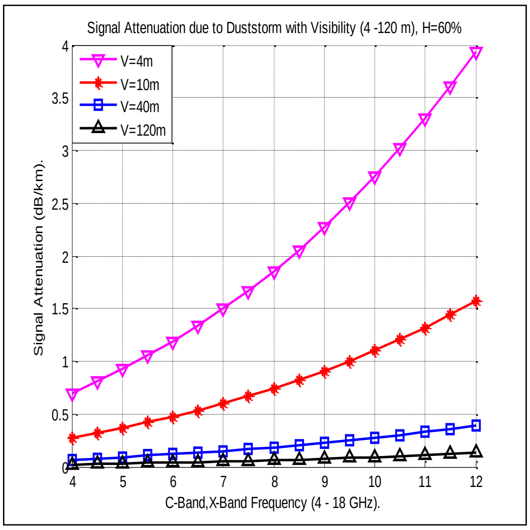

Fig.8: Signal attenuation (dB/km) (humidity 60%)

IV. CONCLUSIONS

This paper stemmed from the idea that the ability to predict channel attenuation due to atmospheric conditions can enable mitigation of channel fading condition by adaptively selecting appropriate propagation parameters. More specially, at high frequency bands the effect of weather attenuation was significant that an efficient and dependable method for estimating the effect of dust storm essential for designing efficient systems. In this context, an analysis of dust storm impact on wireless signal propagation was presented. Investigation considered the dust storms that occur over the mentioned area. Thus, showing the characteristics of dust storm in terms of visibility, particle size. Visibility value has a significant role in the mathematical model used to predict signal attenuation due to dust storm. Measurements at existing microwave links in Libya show that the dust storms can potentially result in serious attenuation in signal level especially at higher frequencies with direct impact on telecommunications system performance. Future work is in progress to consider the different impacts on QoS in the presence of other atmospheric conditions, as well as applying enhanced methodologies to improve communication systems by considering other options.

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