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Prediction of Microwave Signal Attenuation due to Dust and Sand Storms at (4-18 GHz) :Case of study (south of Libya)

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Abstract Dust and sand storms attenuation is one of the major problems in utilization of microwave bands for terrestrial and satellite communication especially at desert areas. This paper present and implement a mathematical model to predict the microwave signal attenuation due to dust and sand storm in the southern region of Libya. The main input parameters for the model are visibility, signal frequency, the volume of dust particulars and humidity. The presented model effectively predicts the microwave signal attenuation. The results show that the attenuation increases with frequencies and humidity and decreases with visibilities. The study found out that the highest values of attenuation in south of Libya varies from 0.13to 9.78dB/km at humidity 60% at Ku-frequencies. The outcome of this study will facilitate the design of reliable communication systems via considering wireless attenuation characteristics due to atmospheric conditions which can enable mitigation of channel fading condition by adaptively selecting appropriate propagation parameters.

Keywords: Attenuations, Dust and Sand Storm, Libya, Microwave, Communication.

التوهين في إشارة الموجات الدقيقة (الميكروويف) نتيجة العواصف الرملية والغبارية

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الملخص: يعد توهين الإشارة (الفقد في الإشارة) الناجم عن العواصف الترابية والرملية أحد المشكلات الرئيسية في استخدام نطاقات الموجات الميكروية للاتصالات الأرضية والفضائية خاصة في المناطق الصحراوية وشبه الصحراوية، مثل جنوب ليبيا. في هذه الورقة قدنا نموذجاً رياضيا تم تطبيقه في برنامج الماتلاب لدراسة وتوقع تأثير العواطف الرملية والغبار على اشرة الأقمار التلفزيونية وحساب قيمة الفقد بدقة، آخذا في الاعتبار الموقع الجغرافي والقراءات الجوية طوال السنة ودرجة الحرارة وخصوصية العواف الرملية بالمنطقة وعلى الرؤية المقدرة وحجم ذرات الغبار.

الكلمات المفتاحية: التوهين، العواصف الرملية والغبارية، ليبيا، الميكروويف، اتصالات.

1. Introduction

Different weather conditions such as rain, snow, scintillation, humidity, sand and dust storms play significant role in causing propagation impairments on satellite signals. These verity of impairments depends upon the severity of weather conditions observed i.e. Dust and sand (DUSA) will cause attenuation, but a severe DUSA may lead to satellite link unavailability. Rain and Snow attenuations are dominant in areas such as America ,Europe, etc., whereas sand and dust storms are observed in different areas around the world as in middle east. So, the major attenuation contributing factor varies depending upon the regional meteorological conditions. Early researches were focused on the attenuation of the DUSA as a uniform distribution or took a specific geometric shape. This approximation gave appropriate results during high or moderate visibility; however it will not provide the designers with respectable results at low visibility (Harb et al.,2012). Signal attenuation due to dust and sand storms were really under investigation, in south of Libya for several decades.Dust storms are significant meteorological phenomenon that occurs for a considerable percentage of time in the Libya. Recent years records show that a phenomenon rate is increasing due to the global environmental. Wireless communication networks and microwave systems have been installed in the southern part of Libya, where there are dust and sand storms that may affect 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 by the sand and dust particles(Abuhdima and Saleh.,2010). The main object of this paper is to determining the attenuation of the wireless microwave communication links subject to sand and dust storms on in the southern region of Libya (Sebha, Ashati, Obari, Morzok, Ghat) by. The result showed that there are some considerations that has to be taken into account in the locations of land communication stations.

2. Concept of Dust Storm Layers

The intensity of dust storm is not uniformly distributed and it varies both horizontally and vertically with the highest in the middle and lowering around the horizontal start, end and vertical edges. It contains several layers while moving from the base, in vertical direction, to the top. These layers represent different levels of visibility based on non-uniform particle size and intensity distributions within the DUSA as shown in Figure . 1. This figure displays the dust storm for different height layers and visibilities. Thus, the visibility increases to its maximum at the highest level of dust storm. The results were acquired for up to 2 km in dust storms altitude along with different estimated visibilities. Such as, for 1.8 km of visibility, the height will be equal to 1.2 km. The physical representation of dust storm according to visibility variations with different levels shall lead to an improved estimation of weather attenuation (Harb et al.,2013).

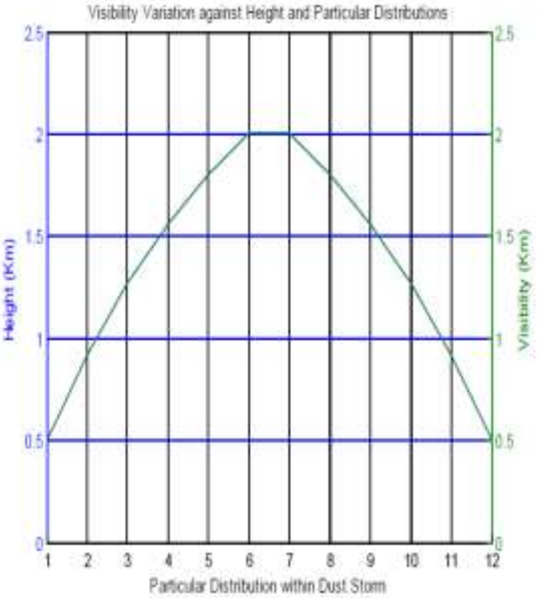

Fig1.Visibility variation of dust storm according to different height (Harb et al.,2013).

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 (Harb et al.,2013).

3. Single-Particle Scattering

Microwaves 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 .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).

Signal Attenuation due to Dust storm

The methods of predicting the signal attenuation due to rain effects can be applied for dust storm because the general model for scattering in sand and dust particle populations is essentially the same as that for a population of hydrometeors; both of them are discrete random medium. The signal attenuation due to dust storm is estimated generally by solving the forward scattering amplitude function of a single particle. The solution may be carried out using 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 (Elabdin et al., 2008):

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

Where Ap (dB/km) is the specific attenuation characterizing the precipitating particles .The following expression is used to calculate the attenuation due to rain (Elabdin et al., 2008):

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

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 .

Dependence on Visibility

To calculate the attenuation by the eq. 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):

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

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):

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

4. Analytical Models for Scattering

Two 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(Elshaikh et al ,.2009). 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(Chu,1976) .

The expression of the total cross-section efficiency factors (σ_t) using Mie solutions as(Collin,1985):

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

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(Elabdin et al., 2008; Elshaikh et al., 2009):

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

$$C_2 = \varepsilon'\left\{\frac{6\times7\varepsilon'^2+7\varepsilon'^2+4\varepsilon'-20}{5[(\varepsilon'+2)^2+\varepsilon'^2]^2} + \frac{1}{15} + \frac{5}{3[(2\varepsilon'+3)^2+4\varepsilon'^2]}\right\} \quad (7)$$

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

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 (Sharif,2015):

$$\varepsilon' H = \varepsilon' + 0.04H - 7.78\times10^{-4}H^2 + 5.56\times10^{-6}H^3 \quad (9)$$

$$\varepsilon'' H = \varepsilon'' + 0.02H - 3.71\times10^{-4}H^2 + 2.76\times10^{-6}H^3 \quad (10)$$

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

5. The Predicting 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 (Elabdin et al., 2008):

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

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 (Elshaikh et al ,.2009;Elabdin et al., 2008; Sharif,2015):

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

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

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

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 Ad(dB/km) as (Elshaikh et al ,.2009)

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

Where $a_e$is the equivalent particle radius in meters, V is the visibility in kilometer 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 dielectricconstant of the particles as (Elshaikh et al ,.2009;Elabdin et al., 2008):

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

$$y = 137\times10^3.\varepsilon'\left\{\frac{6\times7\varepsilon'^2+7\varepsilon'^2+4\varepsilon'-20}{5[(\varepsilon'+2)^2+\varepsilon'^2]^2} + \frac{1}{15} + \frac{5}{3[(2\varepsilon'+3)^2+4\varepsilon'^2]}\right\} \quad (16)$$

$$z = 379\times10^4\left\{\frac{(\varepsilon'-1)^2(\varepsilon'+2)+[2(\varepsilon'-1)(\varepsilon'+2)-9]+\varepsilon'^4}{[(\varepsilon'+2)^2+\varepsilon'^2]^2}\right\} \quad (17)$$

6. Result and Discussion

The southern part of Libya was chosen as the study region for measuring the impact of dust and/or sand storms on the wireless communication systems such as mobile phone and microwave links, because the region has a desert climate and fast wind filled with dust from time to time. Climate information for the region of study, was obtained from weather station, we refer to the Libyan centre of metrology for getting the metrological data of the site selected. In table 1 the minimum value of thevisibility about 4m,the highest average percentage of humidity was recorded from 20 to 51% and the maximum rate of humidity wasrecorded about 60%.The average complex permittivity of thesamples collectedin the studied region is equal to 6.3485 and 0.0929 respectively, the particle diameters generally vary from 1 µm to100µm (Abuhdima and Saleh.,2010).

Table 1.Show the used parameters to calculate the attenuation (Abuhdima and Saleh.,2010)

The parameter	The Value		
Humidity (H)	20 to 51% Maximum rate of humidity was recorded about 60[1]		
Average complex permittivity	Band	Dry Media	Humid Media
	S	4.56 +j0.251	5.63 + j0.90 [10]
	X	5.73 +j0.415	6.8 + j1.054 [10]
	Ku	5.50 +j1.300	6.57 + j 1.94 [10]
Particle diameters	1 µm to100µm[3]		
Visibility	4 t0 120 m		

A mathematical model presented in section 5 , to predict the specific attenuation introduced by dust and sand storm, over microwave links in south of Libya was implemented in MATLAB .This model is deals with all possible ratios of dust and sand particles diameter to wavelength and predict attenuation in microwave wave band with high reliability. In this model, the term visibility (V) is applied to denote the degree of dust storm density instate of total number of dust particles (N),The model expressed the wireless channel attenuation as a function of that the microwave signal attenuation due to dust storm depends on visibility, frequency, dust particle radius , dielectric constant and humidity.

The results in the tables below showed that the attenuation of microwave signal, for sand particle average value of the diameters radius equal to 50μm and visibility between 4 to 120m, increases with frequencies and humidity and decreases with visibilities. The attenuation varies from 0.0045 to 0.66dB/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 to0.66 dB/km with a humidity equal to 0%, and from 0.13to 9.78dB/km at humidity 60%.

Table 2. Variation of sand attenuation (dB/km) for frequency , visibility with 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 3. Variation of sand attenuation (dB/km) for frequency , visibility with 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 4. Variation of sand attenuation (dB/km) for frequency , visibility with 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 5 . Variation of sand attenuation (dB/km) for frequency , visibility with 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

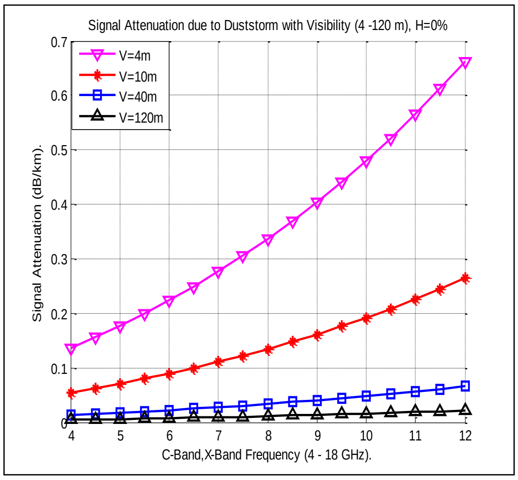

Fig2. Signal attenuation (dB/km) Vs frequency at C-band and X-bandfor humidity 0%.

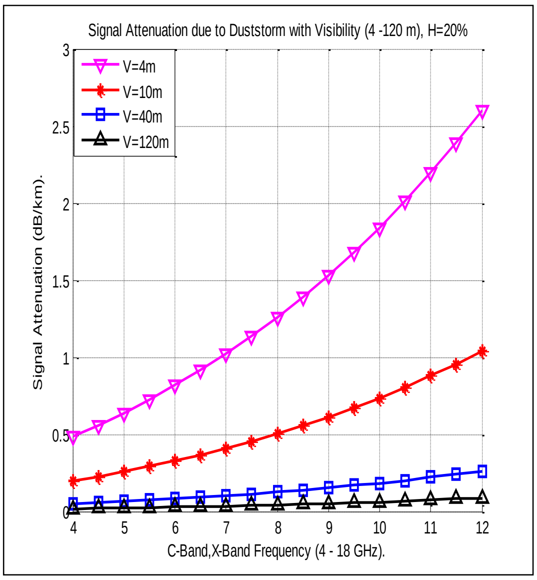

Fig 3. Signal attenuation (dB/km) Vs frequency at C-band and X-bandfor humidity 20%.

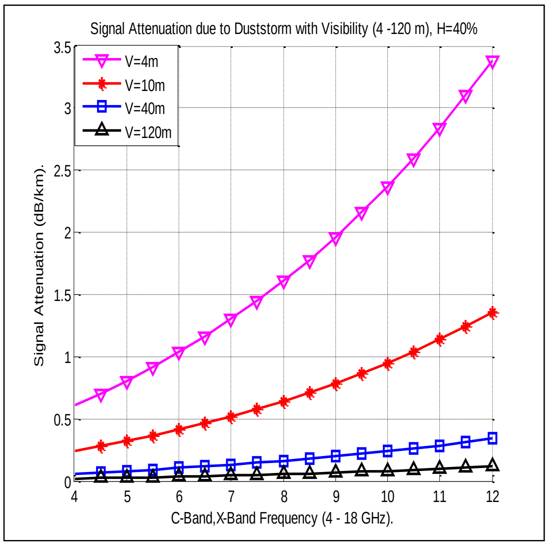

Fig4. Signal attenuation (dB/km) Vs frequencyat C-band and X-bandfor humidity 40%.

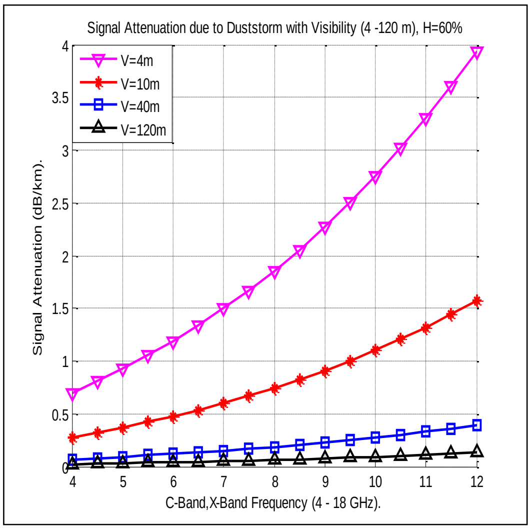

Fig 5. Signal attenuation (dB/km) Vs frequencyat C-band and X-bandfor humidity 60%.

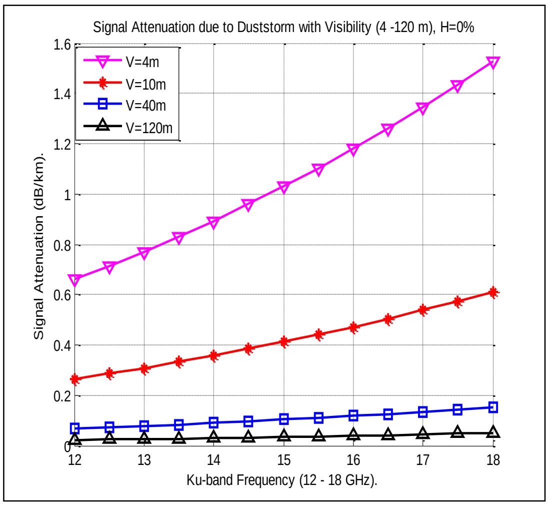

Fig 6. Signal attenuation (dB/km) Vs frequencyat Ku –band for humidity 0%.

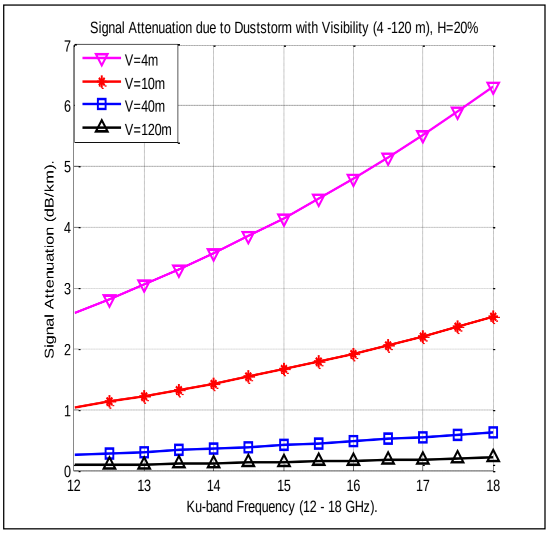

Fig7. Signal attenuation (dB/km) Vs frequencyat Ku –band for humidity 20%.

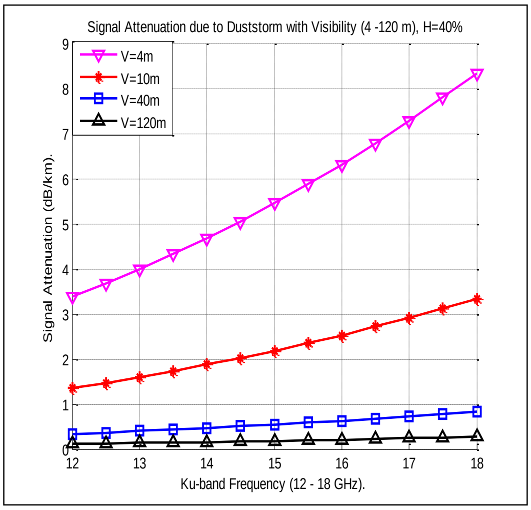

Fig 8. Signal attenuation (dB/km) Vs frequencyat Ku –band for humidity 40%.

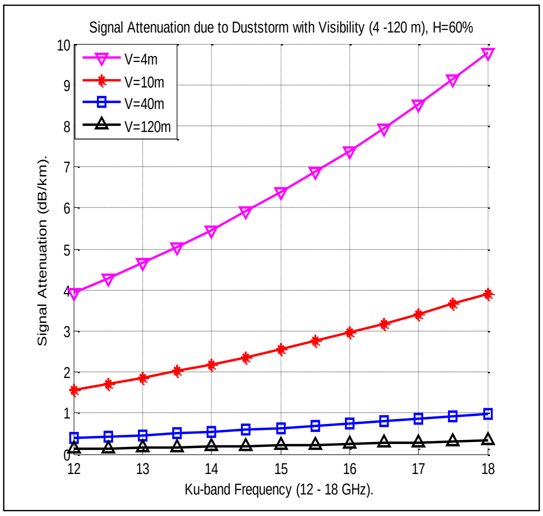

Fig 9. Signal attenuation (dB/km) Vs frequencyat Ku –band for humidity 60%.

7. 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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