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Effect of Wind and Humidity on Microwave Links in North West Libya

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***Abstract*—**The propagation of microwave is affected by rain and dust particles causing signal attenuation and de-polarization. Computations of these effects require knowledge of the propagation characteristics of microwave and millimeter wave energy in the climate conditions of the studied region. This paper presents effect of wind and humidity on wireless communication such as microwave links in the North West region of Libya (Al-Khoms). The experimental procedure is done on three selected antennae towers (Nagaza station, Al-Khoms center station, Al-Khoms gateway station) for determining the attenuation loss per unit length and cross-polarization discrimination (XPD) change. Dust particles are collected along the region of the study, to measure the particle size distribution (PSD), calculate the concentration, and chemically analyze the contents, then the dielectric constant can be calculated. The results show that humidity and dust, antenna height and the visibility affect both attenuation and phase shift; in which, a few considerations must be taken into account in the communication power budget.

Keywords—Attenuation, scattering, transmission loss.

I. Introduction

PROPAGATION on studies at millimeter wave frequencies is of great importance as lower frequency spectrum is getting over crowded. The effects of sand and/or dust storms on the propagation have been considered by few researchers. In [1], the author describes PSD of dust samples collected by hydrometer using Pipette method, as well as measuring PSD and different particle moisture contents. The cumulative weight techniques yield almost identical results for all the samples tested [2]. In [3], the author gave a study involved the monitoring of radio links in the millimeter wave and infrared parts of the spectrum in an arid climate.

Dust and sand particle size also plays an important role in the obtained attenuation values; it is very difficult to measure the radius of dust particles and the density of dust in the air. In dust storm, the particle sizes accumulated in air are non-uniform (i.e. making a mixture of particles with different radii).

The problem becomes complicated since some authors have claimed that the dust PSD is wind speed dependent [4], [5] while others reported that the distribution is independent of wind speed [6]. Similarly, more than one distribution may exist during a storm [7]. For each specific condition, measurement and proper fitting of the probable distribution are necessary to achieve accurate impairment prediction [8]. The forecast of visibility during a dust and sand storm is very difficult [9].

Libya has the longest coastline overlooking the Mediterranean, 1770 km long [10]. It has a Mediterranean climate; both radio relay links and satellite communication systems are used to convey voice, data, and/or image signals all over the country.

Dust and dust storms are frequently encountered in Libya, reducing visibility to hundreds of meters. The Al-Khoms area, which is located in north-west Libya, has a high wind speed, rains, frequent dust storms and high humidity which may last for days. Soil adds some suspended mineral parts to the dust which affects the antennae.

The study of the effect on wireless communication networks due to dust and sand storms has been carried out by many researchers in countries like Libya [11], [12]

In this work we attempt to place bonds on the effects of dust storms and humidity particularly attenuation and depolarization on wireless communication such as microwave links in the west north region of Libya (Al-Khoms city). The calculations are based on meteorological data collected at Al-khomes city for the past 15 years. The soil samples have been collected at three sites, namely Nagaza station, Al-Khoms center station, Al-Khoms gateway station. The dust samples were collected from three different heights of each antenna in the three locations.

II. Visibility in Dust Storm

Visibility or optical visibility forms a critical factor in the attenuation prediction calculations. The attenuation that occurs on a propagating Electro Magnetic Wave (EMW) through dust storms increases as the visibility decreases. Long-time duration of low-visibility dust storms will have more impact on the propagating wave, especially the attenuation.

A. Visibility and Mass Concentration

Patterson and Gillette [13] studied the relation between the visibility and the particles' mass concentration to determine the particulate concentration in the atmosphere. This relation provides another mean of finding the visibility from the

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particles mass concentration and vice versa.

If M is the particulate mass concentration, V is the visibility and C is a constant, the relation between the mass concentration and the visibility can be given by [13]:

$$MV^{\gamma} = C \quad (1)$$

where γ is constant.

B. Visibility Variation with Height

Visibility during dust storms decreases as the height increases. One can logically understand that tall antennas will perform less than short antennas during sand storms. The authors [14] gave the following empirical relationship between the dust mass concentration (*M, kg/m*^{3}) and the height (*h, m*):

$$M = a / h^{b} \quad (2)$$

where a and b are constants depending on dust PSD, geographical and climatic conditions. The authors [15] believed that constant C value for Libya is C= 2.3x10^{-5} kg/m^3 and γ =1.07 are applicable. By substituting for M from (1), (2) can be written in terms of visibility as:

$$V^{\gamma} = Ch^{b/a} \quad (3)$$

Let *Vo* be the visibility at some reference height *ho.* Thus (3) can be rewritten as:

$$V^{\gamma} = V_0^{\gamma}\left[h / h_0\right]^{b} \quad (4)$$

From measurements of dust concentration and visibility, the following relationship between visibility V (in km) and mass density ρ (in gm/cm^3) can be obtained [1]:

$$\rho = \frac{C}{v * V^{\gamma}} \quad (5)$$

where υ is the relative volume occupied by particles (m^3 of particles/m^3 of air).

III. The Dielectric Constant of Dust and Sand

The understanding of the dusty medium, dust storm, and dielectric properties is essential to investigate the medium effects on the microwave signal propagating through. The complex dielectric constant forms the main dielectric properties of the dusty medium. It is an important component in the attenuation prediction mathematical models [1].

The mathematical models require knowing the insulation constant of the mixture (ε_m) which depends on the composite buffer of the material (εi) and its relative size ((υi). Using Looyenga equation to calculate the compound permittivity of the composite component as:

$$\varepsilon_m{}^{1/3} = \sum_{i=1}^{n} v_i \varepsilon_i{}^{1/3} \quad (6)$$

where: ε_m the complex dielectric constant of the mixture. εi is the complex dielectric constant of the ith substance. v_i is the relative volume of the ith sample from the volume of the total sample. The permittivity of materials at microwave frequencies is $\varepsilon = \varepsilon' - j\varepsilon''$, where ε' is referred to the dielectric constant and ε'' is the dielectric loss factor. The complex permittivity also depends on frequency of operation and moisture content. In general, the moisture causes increase of both real and imaginary parts of the complex permittivity which depends on chemical composition of dry soil samples [15], [16].

IV. Measurement and Analysis

Pertaining to the region specific variation in chemical and physical properties of dust and sand, several experimental details related to PSD have been gathered for samples of Al-Khoms area. The region is important for the Libyan microwave communication network, where it links north Libya to its south east and west. Collection sites' details are mentioned in Table I.

TABLE I
HIGH AND LOCATION OF TOWERS

Station	Latitude (N)	Longitude (E)	Tower (H.m)	Distance between towers (km)
Nagaza stations	32^0 41' 24''	14^0 06'36''	65	_
Al-khoms center stations	32^0 39'00''	14^0 16 12''	45	15.53
Al-khoms gateway stations	32^0 38' 36''	14^{0}14' 24''	60	13.86

Eight samples from the several different heights were collected from 2 m to 40 m for each tower. The distance was measured from the surface of earth (above the roof of the station). The sand samples were collected from the ground of the stations.

A. Meteorological Data for the Regional Study

The metrological data for the locations of the stations were provided by the national metrological center. The data were collected over 18 years (1991-2006); the data shown in Fig. 1 comprise of the monthly average relative humidity, Max Temp. (^{o}C), Min. Temp. (^{o}C), R. Humidity %, wind speed (km/h) and Rainfall Q. (mm). From the presented data, the following summary can be pointed out:

(1) The highest average temperature was recorded from 18 to 32 °C.
(2) The highest average percentage of humidity was recorded to be 73.1666%.
(3) The wind speed recorded from 6.3 to 7.6 km/h.
(4) The proportion of rainfall recorded from 0.2 to 65.8 mm.
(5) The maximum temperature recorded 32 °C.
(6) The maximum rate of humidity was recorded about 75%.

A. Analysis of the Samples

One of the simplest methods to compute the dielectric constant and attenuation factors is to measure PSD, average density and chemical composition, It is important to do some analysis for samples in that application.

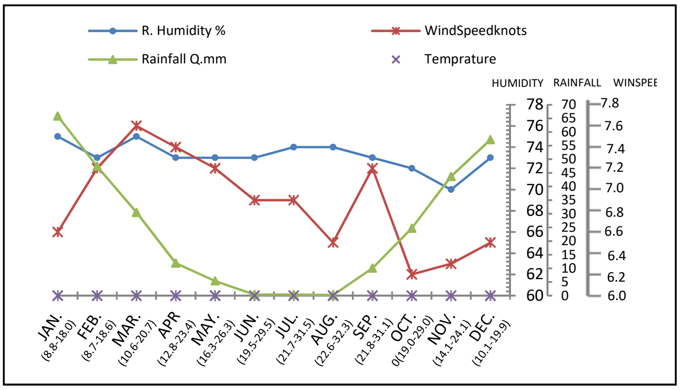

Fig. 1 The relative humidity, wind speed, rainfall, and temperature for the studied period

TABLE II
CHEMICAL ANALYSIS OF SAMPLES

Oxide	Sample(1)	Sample(2)	Sample(3)	Sample(4)	Sample(5)	Sample(6)	Sample(7)	Sample(8)
	Mass %	Mass %	Mass %	Mass %	Mass %	Mass %	Mass %	Mass %
SiO_2	47.23	40.71	38.28	17.91	47.92	37.99	37.61	43.9
CaO	24.47	33.63	24.92	25.23	18.11	31.55	27.73	20.89
Al_2O_3	6.9	6.11	8.73	4.33	6.12	7.38	9.79	11.32
MgO	2.22	3.14	3.27	2.52	2.04	2.96	3.56	3.18
Fe_2O_3	2.14	2.25	4	3.26	2.31	3.12	4.49	4.77
K_2O	2.01	1.33	2.24	1.18	1.75	1.66	1.75	2.04
SO_3	2.6	0.883	3.63	7.77	0.291	1.94	0.808	0.458
Na_2O	0.805	0.614	1.99	5.8	0.418	1.27	0.89	0.736
CL	0. 417	0.239	1.17	6.58	0.0687	1	0.488	0.306
LOI	10	10	10	20	20	10	10	10

TABLE III
PSD AND DENSITY OF SAMPLES

Sample No.	Type	Density(g/ml)
1	Dust	1.455
2	Sand	1.724
3	Sand	1.889
4	Dust	1.387
5	Dust	1.676
6	Sand	1.417
7	Sand	1.705
8	Dust	1.832

TABLE IV
COMPLEX PERMITTIVITY OF SUBSTANCES

Compound	complex permittivity
SiO2	4.43 -j0.04
Al2O3	12.66-j1.31
Fe2O3	16.58-j0.93
CaCO3	8.22-j0.12
MgCO3	5.03-j0.17
CaSO4	5.01-j0.08
MnO2	75.74-j26.29

The Lebda Plant in Al-Khoms has equipment that are capable to carry out the chemical composition analysis and Faculty of Engineering (Civil Eng. Department) in AL-Khoms university has PSD, the conductivity, and the density test equipment. The results are shown in Tables II and III. The average density of all samples equals to 1.636 g/m^3.

B. Calculation of the Complex Permittivity for Samples

The complex permittivity (ε′–jε″) depends on chemical composition of soil samples, which are represented in Table IV, which depends on results presented in Tables II and III to estimate the complex permittivity of each sample, as in [11]. The calculated complex permittivity is given in Table V [17]. Complex permittivity of all samples from Table V equals to 2.8098 – j 0.0481.

TABLE V
COMPLEX PERMITTIVITY OF EACH SAMPLE

Sample No.	Type	ε_m
1	Dust	3.0355 – j 0.0717
2	Sand	3.3602 - j0.0788
3	Sand	2.8432 - j0.0825
4	Dust	0.8658 - j0.0240
5	Dust	2.3714 - j0.0555
6	Sand	3.1519 - j0.0826
7	Sand	3.3477 - j0.1014
8	Dust	3.5023 – j 0.1114

C. Estimating Air Relative Humidity

The complex permittivity depends on moisture content of samples. The following empirical relation for the variation of complex permittivity with relative humidity is present and approved in [18].

$$\varepsilon' = 5.52 + 0.04\mathrm{H} - 7.78\times10^{-4}\mathrm{H}^2 + 5.56\times10^{-6}\mathrm{H}^3 \quad (7)$$

$$\varepsilon'' = 0.16 + 0.02H - 3.71\times10^{-4}H^2 + 2.76\times10^{-6}H^3 \quad (8)$$

where H is the air relative humidity (percentage) The first term depends on that for zero humidity of the region.

To estimate the effect of relative humidity on the complex permittivity in the studied area (Al- Khoms region), (7) and (8) are used:

$$\varepsilon' = 4.3619 + 0.04H - 7.78\times10^{-4}H^2 + 5.56\times10^{-6}H^3 \quad (9)$$

$$\varepsilon'' = 0.1263 + 0.02H - 3.71\times10^{-4}H^2 + 2.76\times10^{-6}H^3 \quad (10)$$

D.Calculation of the Attenuation Constant

For dust, the imaginary part of the dielectric constant is very dependent on the hygroscopic water content of the sample; this can be concluded from the variations of the dielectric constant with humidity of the sample. Attenuation dust to scattering depends on the shape of the scattering particles and their orientation relative to the wave polarization, as well as an effect of the height of towers on both the attenuation constants in this region [19].

$$\alpha = \frac{2.46 * 10^5 * v}{\lambda} * \left[\frac{\varepsilon''}{(\varepsilon' + 2)^2 + \varepsilon''^2}\right] \quad (11)$$

$$v = \frac{C}{\rho * V_0^{\gamma} (h/h_0)^b} \quad (12)$$

where *Vo* is the visibility at h_o; its minimum value is about 6.50 m., ho =2m is the reference height

C=2.3 X 10^{-5}, γ = 1.07

ρ= is the average measured density of the samples collected in Al- Khoms region is 1.6356 gm/ml. ε_m= 4.3619 – j 0.1263 is the complex permittivity of dry sample. Fig. 2 shows relationship between attenuation per Km and the humidity

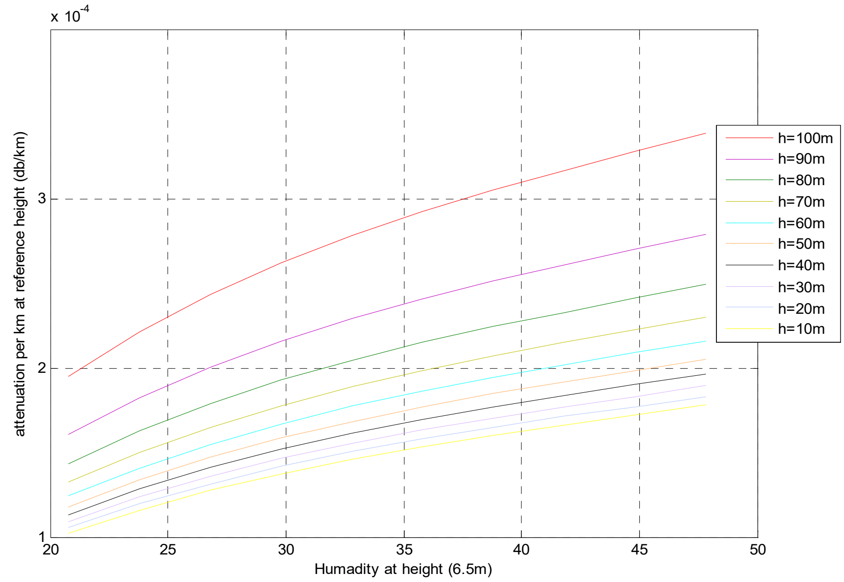

Fig. 2 Attenuation per Km as function of the humidity

V. Conclusions

This research studied the impact of dust, wind and humidity and sand storms on wireless communication system (GSM signal) in the North West of Libya (Al-Khoms); this region has a large number of wireless communication systems. The effect of the dust and sand on the wireless communication systems in this area has been studied in summer of 2017. Also, the effect of the humidity on the complex permittivity and the effect of the height of towers on the visibility were studied along with their effect on both the attenuation and phase shift constants in this region. The average of complex permittivity of dry soil in Al-Khoms for every level 2 m, 2 5m, 28 m, 40 m of study are equals to (3.0355 – j 0.0717), (3.3602 – j 0.0788), (3.3477 – j 0.1014) and (3.5023 – j 0.1114) respectively. From the results, we concluded that:

- The average density of dry soil in studied region for all samples was 1.636 g/ml.
- The cross-polarization expected not to be serious on the wireless communication systems in the region of study, because the shape of dust particles is spherical.
- The value of the attenuation increases as the humidity and frequency increases.
- The value of the attenuation decreases as the visibility increases.

The result shows that humidity and dust, the antenna height and the visibility affect both attenuation and phase shift where some consideration has to be taken into account in the communication power budget.

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