A Proposed Method for Dust and Sand Storms Effect on Satellite Communication Networks

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Abstract—**Due to frequent climate changes in our daily atmosphere, the movement of dust and sand storms has become very severe and unpredictable. The climatic variations affect the propagation of high frequency satellite signals. In order to estimate wireless channel signal impairments, a system has been modeled based on estimated visibility and volume of dust particulars. A new approach for determining visibility based on duststorm model has been presented. Also, this paper presents a new method to fragment the dust storm into different sections based on variations in visibility at different heights. A three-dimensional relationship is presented for dust and sand attenuation (DUSA) and signal to noise ratio (SNR) to show the variations of dust attenuation with both visibility and dust particle volume at different locations. The relationships can be exploited to develop an enhanced back propagation-learning algorithm that can be used to iteratively tune the controller based on weather conditions and by means of SNR feedback values and other satellite parameters. The algorithm applied to a simulated model for activating the weighted Modulation/Codepoint control showed markedly improvements in ensuring optimal configuration settings for any given service level agreement commitment.**

Index Terms—**Decision Support System (DSS), Dust and Sand Storm (DUSA), Duststrom Visibility, International Telecommunication Union-Radiocommunications (ITU-R), Quality of Service (QoS), Signal to Noise Ratio (SNR).**

I. Introduction

Different weather conditions such as rain, snow, scintillation, moisture, sand and dust storms play significant role in causing propagation impairments on satellite signals. The severity of impairments depend upon the severity of weather conditions observed i.e. a duststorm will cause attenuation, but a severe duststorm 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. So, the major attenuation contributing factor varies depending upon the regional meteorological conditions. Early researches were focused on the attenuation of the duststorm 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. Figure 1 presents a real reflection of the dust and sand storm effects on signal quality of service (QoS). Signal attenuation due to dust and sand storms were really under investigation, in Asia especially in Saudi Arabia, for several decades. Researches [1–13] have proposed several models to present this complicated phenomena. Behavior and composition of duststorms seem to be somehow uncorrelated among various regions of the world due to the non-uniformity of the dust characteristics and several other atmospheric factors.

Fig. 1. Influence of Duststorm at KFUPM, Dhahran, Saudi Arabia, in March, 2012.

The severity becomes increasingly debilitating at the higher ends of the high frequencies [3,5,9]. Consequently, it is extremely hard to optimally manage satellite-dependant resources that are impacted by weather attenuations. An effective technical solution to significantly improve the quality of service (QoS) would depend on the ability to properly identify, predict, and qualify the overall impact of individual attenuation factors. A number of models for dust and sand storm attenuations are available for estimating individual attenuation components. However, methodologies that attempt to combine them in a cohesive manner are not widely available [1, 4, 5, 9, 10, 13]. Authors of [10] described a special case of approximated dust distribution of ellipse shape (seen from the top view) of the dust storm, as expanded rapidly until the peak and then shrinking gradually. Also, an effort has been done by authors of [12] to model the vertical variation of the dust storm based on the idea that the visibility during the dust storm in-

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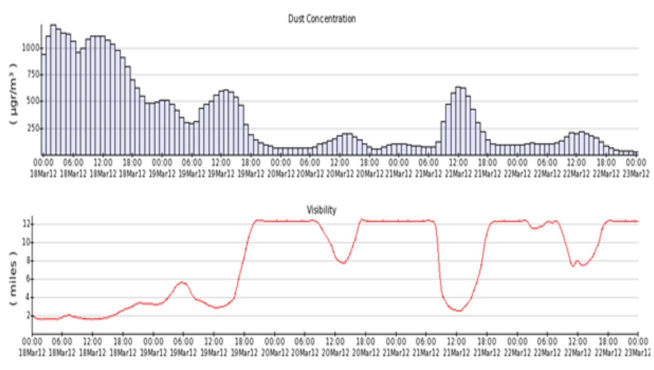

Fig. 2. The Dust Concentration Compared to The Visibility During March 2012.

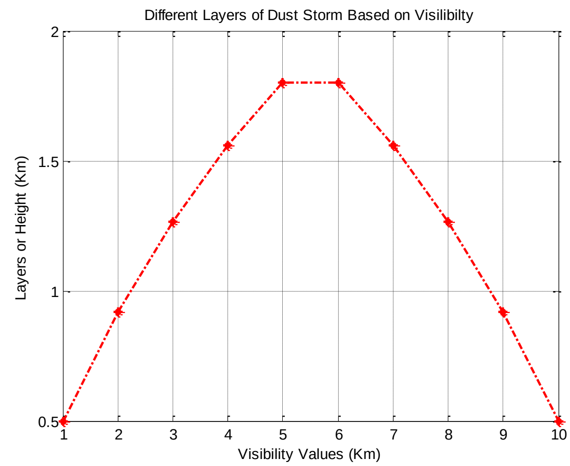

Fig. 3. Different Layers of Dust Storm Based on Visibility.

creases as the height increases. In [13], authors present an estimation of the vertical path adjustment factor according to a specific shape of duststorm.

In this paper, a three-dimensional relationship is presented for attenuation and SNR to show the variation of dust attenuation with both visibility and dust particular volume based on different levels of visibility and dust particle volume at different locations. Specifically, we drove the dust and sand attenuation (DUSA) with respect to visibility, frequency and propagation angle for any given location. Thus, SNR estimation is presented based on different storm levels, frequency and propagation angle to have better estimation of satellite signal propagation under different weather conditions. Thus, the new estimation for signal propagation along a dusty weather provide a clear view to the interconnected network entities, to be ready for unpredicted forecasts which actually manifest in order to maintain end-to-end QoS requirements.

The remaining sections of this paper are as follows: Different Dust layers is described in Section II. In Section III, we present the simulation results and discussions. Finally, we conclude this study in Section IV with future work.

II. Different Sand and Dust Layers

This section describes dust and sand storms which are commonly observed in arid and semi-arid areas on earth. They arise when wind blows off the dust particles from ground and get suspended to the air. These storms are usually observed in different regions of Saudi Arabia round the year, but their frequency increases in the months of March, April and June. Figure 1 was taken at KFUPM in March 2012. It represents how the dust storm impacted the visibility in Dhahran, Saudi Arabia. Also, Fig. 2 shows the dust concentration compared to visibility at earlier times of this year. Our focus here is on the impairments caused by such storms on satellite Communications.

Generally, sandstorms are referred to sand being controlled by winds where the sand particles rarely rise more than few meters. The horizontal movements of sand particles are blown laterally by the wind and at the same time the particles bounce from the surface in a horizontal wind field. The diameters of most sandstorm particles are usually between 0.15 and 0.3 mm. Sand particles are usually comprised of 92% silicon dioxide by weight. Sandstorms are most likely to develop in desert regions where loose sand exist which tends to form during the day and die out at night [14–16].

In addition, the duststorms usually occur over arable land where there has been a drought over extended periods. Strong winds may raise the dust particles, as high as few kilometers depending on location. The particle diameters generally vary from 100 μm to 1 μm. Hence, the fall speeds of such particles are such that the dust may block the sun for some extended periods. To be classified as a duststorm, the visibility must be smaller than 1 Km. When the visibility is shorter than 500 m, it is considered a severe duststorm [14]. Thus, the variation in diameters for sand and dust made the attenuation distribution varies widely across the channel.

In this paper, we divide the dust and sand storms into different layers as shown in Fig. 3. This figure shows the relation of height, at different levels, to visibility that can be presented by the following expression:

$$h_i = h_{(i-1)} \left[\frac{V_i}{V_{(i-1)}} \right]^{-0.26} . \tag{1}$$

The height (h_i) variation with visibility (V_i) can be related to the reference visibility ($V_{(i-1)}$) at a height ($h_{(i-1)}$) by the following expression [12]:

$$V(\theta) = V_0 \left[\frac{h(\theta)}{h_0} \right]^{0.26} . \tag{2}$$

The actual signal path can be calculated according to the propagation angle as:

$$L = \frac{h}{\sin\theta} \quad \Rightarrow h = L \, . \, \sin\theta \tag{3}$$

where L represents the path of length for the satellite signal in Km.

Eq. 1, derived from (2), represents a recursive relationship for height and visibility which leads to present the visibility as a function of propagation angle. Based on our analysis, the characteristic of dust storm layers according to visibility is presented in Fig. 3 as follows:
In Layer-1, greater attenuation would be observed because it has lower visibility as the probability of heavier and denser dust particles would be at its maximum. However, as we move to the second layer and beyond, visibility increases and consequently the probability of denser and heavier particles decreases ultimately constituting less attenuation. After a certain visibility is achieved, we assume the last layer as free space and apply the free space loss formula for attenuation calculation going forward till the satellite. In this way, we breakup the dust storm into different layers and calculate the attenuations caused at individual layers and ultimately add them to get the total attenuation. In our scenario, we start from a reference height and a reference visibility (V_0) and as soon as this reference visibility doubles at a certain height (h_0), we mark that point as the boundary for that layer to start a new layer. This process continues in a recursive manner until a certain visibility is achieved, which is kept as an initial bound on free space.

Based on Fig. 3 , we conclude that, the layering process is based on the fact that as the visibility at the base of a specific layer doubles while moving in a vertical direction, we terminate that layer and start another layer from that point. To be more precise, we can make more layers with fewer difference in visibility values. However, its computational cost will increase. We can declare free space as the visibility attains a certain value.

A. *DUSA Behavior at High Frequency*

DUSA is one of the most common, often misunderstood, and complicated phenomenon that affects satellite signals in Saudi Arabia and other areas. The diameter of a dust also plays a detrimental role in the passage of Ku/Ka-band signals.
Therefore, the ability to estimate signal attenuation due to DUSA plays an important role in our ability to minimize its impact on satellite systems. Signal fading caused by different weather conditions limit the QoS of satellite links and system availability. In order to prevent the loss of signal due to attenuation, satellite service providers transmit signals down with extra power in areas with extreme weather conditions. However, this extra power can not extant certain limits from one side and sometimes this factor will not provide any improvement like when heavy duststorms take effect.

B. *Simulations and Analysis for Dust and Sand Attenuation*

We estimate dust attenuation by using a set of functions and solving them for different values of visibility and particles of dust size. The outcome of these calculations would be dependable values of frequency and propagation angle, which helps the control system to gain an enhanced view of channel conditions.

TABLE I
LISTING OF DIELECTRIC CONSTANTS AT VARIOUS FREQUENCIES MEASURED BY [6, 17–19].

Dielectric Constants Values			
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

In our methodology, we extract the dust attenuation from the following equation:

$$\mathrm{A_P}(\theta, \mathrm{f}) = \frac{(5.67 \times 10^2)}{\mathrm{V}\,(\theta) * \mathrm{r}_{\mathrm{e0}}^2 * \lambda} * \frac{\varepsilon''}{(\varepsilon' + 2)^2 + \varepsilon''^2} * \sum_i^n p_i * r_i^3 \tag{4}$$

where: A_p is the point attenuation in dB/Km as a function of propagation angle and frequency.
V Visibility in Km.
r_{e0} Equivalent particle radius.
λ Wave length.
ε'', ε' Real and imaginary parts of the dielectric constant.
$\sum_i^n p_i * r_i^3$ Summation of the probability particle size between ri series of particle volume.
i, n reprent the lowest and heightest layer level.

Hence, this model helps and provides control center with a dependable estimate of dust values for any desired location (X and Y) according to different visibility, dust particle size, wide frequency ranges (f), and for any propagation angle (θ) as shown in Fig. 4. Thus, knowing this data will be an immense asset to support analysis for budgeting the operational satellite networking parameters at any specific location.

Weather attenuations can have a distorting effect on signal fidelity above 10 GHz, and thus leading to increase the bit error rate (BER) of digital transmission. A reliable system is necessary for improving signal to noise ratio (SNR) by using estimated atmospheric attenuations and other factors under extreme signal to weather conditions.

C. *Algorithmic Basis for SNR Calculation*

In satellite communications the most prominent contributors to noise beside rain are duststorm and free space. The most important four features of free space are its uniformity everywhere, absence of electrical charge, no current flowing through it, and its infinite extent in all directions [20, 21].

Calculate the thermal noise power spectral density as: $N_0 = K \cdot T$, where Boltzmann constant $K = 1.38 \cdot 10^{-23}\ Ws/K = -228.6\ dBWs/K$ and effec-

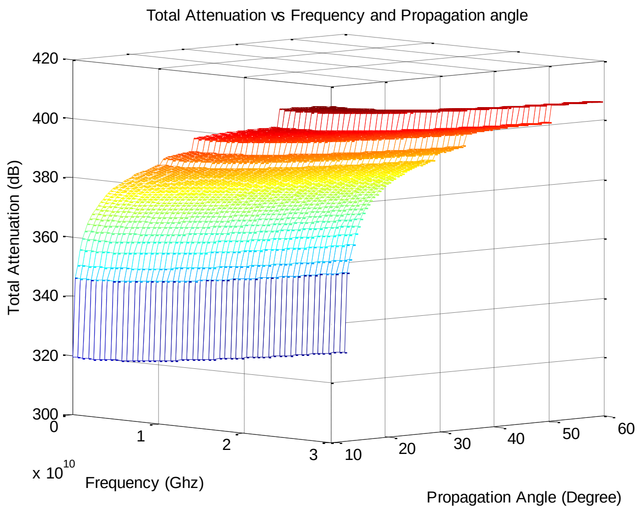

Fig. 4. Total Attenuation at KFUPM, Dhahran, Saudi Arabia.

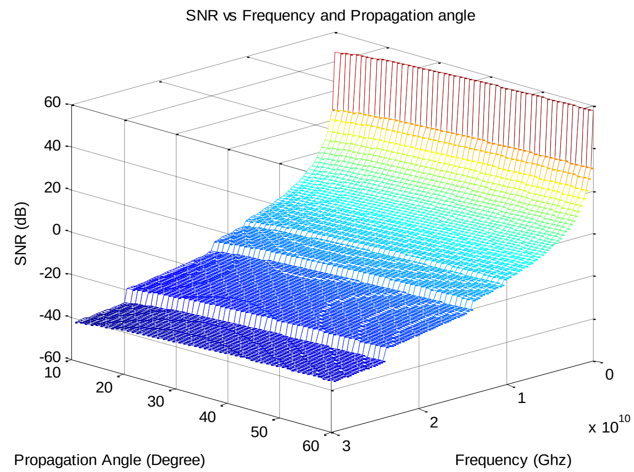

Fig. 5. Estimated SNR at KFUPM - Dhahran, Saudi Arabia.

TABLE II

TA: Antenna Noise Temperature (*Kelvin*)		
Directional satellite antenna	Earth from space	$290\ K$
Directional terminal antenna	- Space from earth at $90°$ elevation - Space from earth at $10°$ elevation - Sun ($1...10\ GHz$)	$3-10\ K$ $\approx 80\ K$ $10^5...10^4\ K$
Hemispherical terminal antenna	- At night - Cloudy sky - Clear sky with sunshine	$290\ K$ $360\ K$ $400\ K$

tive noise temperature $T = T_a + T_r$, T_a is noise temperature of the antenna as represented in Table II, and T_r is noise temperature for the receiver represented as $\mathrm{T_r} = (10^{N_r/10} - 1) \cdot 290$, with noise figure of low-noise amplifier, $N_r \approx 0.7 \sim 2\ dB$. Thus, the ratio between signal and noise power spectral density is:

$$\frac{C}{N_0} = \frac{C}{K \cdot T} = \frac{P_r}{K \cdot T} = \frac{P_t \cdot G_t}{A_t} \cdot \frac{G_r}{K \cdot T} \tag{5}$$

where A_t (Total Attenuation) $= A_r$ (Rain Attenuation) $+$ A_0 (Free Space Loss), such as $A_0 = (4 \cdot \pi \cdot d / \lambda)^2$, where d is the distance between transmitter and receiver and the wavelength $\lambda = c/f$.

As E_s (symbol energy) $= C \cdot T_s = C / R_s$, where transmission rate R_s (symbol/sec) is inversely equivalent to symbol duration T_s, and energy-to-noise power density per symbol is:

$$\frac{E_s}{N_0} = \frac{C}{N_0} \cdot T_s = \frac{C}{N_0} \cdot \frac{1}{R_s} \tag{6}$$

or

$$\frac{E_s}{N_0} = \frac{C}{N_0} - R_s \quad dB. \tag{7}$$

$$SNR(A_t, P_t) = P_t + G_t - A_t + G_r - T - K - R_s \quad dB \tag{8}$$

where P_t and P_r are transmitter and receiver power, and G_t and G_r are antenna gain at transmitter and receiver sides respectively. It should be noted that the SNR estimation of (5) will be optimized by the virtue of having better estimation of A_t through (8).

III. Simulation Results and Discussions

In the previous sections, we presented the computation of the dust attenuation at KFUPM for different visibility and dust particle values, with different propagation angles, and for a wide range of frequency. These results, shown in Fig. 5, give us a clear view about the variation of SNR with different propagation angles and frequencies. Moreover, these results can be used as key factors in implementing an intelligent engine that act to improve end-to-end wireless communications for different weather conditions.

Fig. 5 considers the case where SNR falls between $(-60 \sim +60)\ dB$, for frequency from $(0 \sim 10\ Ghz)$ and propagation angle from $(10 \sim 60\ degrees)$.

The results are done at KFUPM station - Dhahran, Saudi Arabia, by using Matlab simulations version 7.1 running on Intel Centrino Pentium M 1.6 GHz CPU, 512 MB RAM, where the program was written to simulate input data from different sources such as ITU-R, to implement the three dimensional results for total attenuations, and for SNR in order to present the desired output for the communication of satellite systems.

IV. Conclusions and Future Work

This work 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. Especially at high frequency bands, the relative effect of weather attenuation was so great that an efficient and dependable method for estimating duststorm was considered essential for designing efficient systems. This paper presented an analysis to duststorm effect on signal propagation. Duststorms are significant meteorological phenomenon that occur for a significant percentage of time in the Saudi Arabia and other countries of Middle East and Sudan. Recent years records show that a phenomenon rate is increasing due to the global environmental changes. Investigation is on the duststorms that occur over the mentioned area in the previous years. Thus, showing the characteristics of duststorm in terms of visibility, wind speed and distance. Visibility data have a significant role in the mathematical model used to predict signal attenuation due to duststorm. Measurements at existing microwave links in Saudi Arabia show that the duststorms 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 satellite systems by considering other options.

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