Preliminary Analysis of Dust Effects on Microwave Propagation Measured in Sudan

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Abstract. Dust storms are meteorological phenomena which occur for a percentage of time in arid and semi arid areas especially at African Sahara and Middle East. Measurements at existing microwave links have showed dust storms can potentially result in serious attenuation in signal level especially at Ku band and higher frequencies with direct impact on telecommunications system performance. Only a limited amount of research has been carried out and the available data was very scarce. Few prediction models have been developed to estimate microwave signal attenuation during the dust storm based on scattering theory and approximation of dust properties. However, real dust storm is a complex phenomenon which is difficult to be described by theoretical physical or mathematical models [5-6]. In this paper, an evaluation of the existing attenuation prediction models has been done based on the measured dust storm properties and measured attenuation in Sudan.

1. Introduction

It has been realized that attenuation is higher at frequency bands above to 10 GHz due to the sensitivity to weather conditions. Consequently, rain, snow, cloud, fog, dust storms and other phenomena cause signal attenuation which can seriously limit the performance of wireless communication systems[1-4]. Microwave signal attenuation due to dust storm is one of those potential problems and technical challenges need to be investigated in order to provide reliable wireless communication services[5-7]. Sand and dust-storms occur in many parts of the world, especially in the Middle East and arid parts of Asia, as well of Southwest USA, in the dry states such as Texas and Arizona.

Dust storms are becoming more frequent in some parts of the world; there is significant correlation between the increased occurrences of dust storm and the climate change phenomenon. From figure 1 it is obvious that the dust storm phenomena is increasing in recent years[8-9].

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Dust storms affect the microwave propagation and it is severe in high frequencies. It attenuates the signal and degrades the performance of microwave links especially in arid region\cite{10}. Limited research has been conducted in dust storm attenuation area. The scarcity of measured data forces researchers to work for the dust storm prediction modeling. Few theoretical models have been developed based on single scatterer, multiple scattering or mutual interaction phenomena \cite{1-3, 11-13}.

2. Measurement setup

Microwave links at 12GHz-13GHz and different lengths have been installed in Khartoum as shown in Fig. 2 and Table 1. All terrestrial links have been monitored and the transmitted and received signal levels have been recorded for one year. The corresponding visibility data have been collected from the meteorological department.
Table 1: Details of the four terrestrial links that are used for the study.

| link      | Location   | Frequency MHZ | Length Km |
|-----------|------------|---------------|-----------|
| JERRAIF SOBA | E 32°36´8.70 N 15°36´29.90" | 12765-12905 | 13031-13171 | 12.97 |
| SOBA MODRAAT | E 32°29´56.00 N 15°32´41.50" | 13031-13171 | 12765-12905 | 15.22 |
| MODRAAT Omdurman | E 32°29´56.00 N 15°36´19.10" | 12765-12905 | 13031-13171 | 7.19 |

Two attenuation prediction models have been evaluated using the analyzed dust particle properties, and based on the measured visibility and attenuation.

3. Dust Storm Prediction Models

Different approaches have been adopted to evaluate microwave signal attenuation due to dust storm in terms of its characteristics such as the number of dust particles per cubic meter, the mass of dust per cubic meter or visibility. Therefore, various investigations showed that the scattering of electromagnetic waves propagating in dust storms is influenced by various factors including incident wave frequency, permittivity, density, geometric scale, distribution of grains, moisture and chemical behavior of dust particles[14].

Two recent attenuation prediction models have been investigated. These models have been based on certain assumptions but rely on some empirical inputs such as particle shape, chemical composition, size and dielectric constant.

3.1 Chu’s Modified by Goldhirsh Model (1982)

Goldhirsh [1] has modified Chu’s model by expressing the specific attenuation coefficient as a function of visibility and particle size distribution as follows.

\[
\Lambda = \frac{5.67 \times 10^2}{\sqrt{\lambda r_e^2 \rho}} \times \frac{\epsilon'}{(\epsilon' + 2)^2 + \epsilon''^2} \sum P_i r_i^3 \quad [\text{dB/km}] \tag{1}
\]

where
- \( r \) = particle radius in meters.
- \( \lambda \) = wavelength (m).
- \( \epsilon' \), \( \epsilon'' \) = complex dielectric constant of dust particles.
- \( V \) = visibility (m)
- \( r_e \) = Equivalent particle radius in meter.

Although, Chu modified model has attained close agreement between predicted and measured attenuation, the model loses its reliability when used to predict attenuation above 37GHz [14-15].

3.2 Elshaikh Model (2008)

Elshaikh.Z.[15] has proposed a prediction model based on Mie scattering which can calculate the specific attenuation in microwave wave band with high reliability. The model has related attenuation coefficient to the visibility, particle size distribution.
\[ A = \frac{r_e f}{V} (x + yr_e^2 f^2 + zr_e^3 f^3) \text{ [dB/km]} \] 

(2)

where

\[ r_e = \text{ Equivalent particle radius in meter.} \]
\[ V = \text{ Visibility in kilometer.} \]
\[ f = \text{ Frequency in GHz.} \]

\[ x = \frac{1886 \times \varepsilon'}{(\varepsilon'+2)^2+\varepsilon'^2} \] 

(3)

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

(4)

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

(5)

4. Measurements

In the study conducted by the author, a duststorm was monitored on September, 2008 in Khartoum- Sudan. One of most severe dust storm occurred on 21st of September. Dust storm attenuation measurements recorded by Marconi microwave system which monitoring a microwave network providing cell phone services in Sudan. Figure 3 and 4 show a record of microwave signal level during the storm. On the other hand, Sudan meteorological Authority recorded a visibility less than 50 m during the storm.

![SOBA_MUD](image_url)

Figure 3: Measured signal level for soba –MUD link on 21st September 2008.
Figure 3 showed that measured total attenuation for SOBA_MUD link was equal to 32 dB at 13GHz and 15.2 km link. Whereas, Figure 4 showed the measured total attenuation for SOBA_JERRAIF link equal to 36 dB at 13GHz and 13 km link length.

5. Predicted attenuation

Dust storm attenuation was predicted using models proposed by Goldhirsh and Zain with the parameters $r_e = 38 \mu m$, $e'=4.2$, $e''=1.56$, $V=50 m$ and $f=13 GHz$. Equations (1) to (5) were used to estimate the attenuations and presented in Table 2. Measured and predicted attenuation are compared in Table 3. It is obvious that the measured attenuation are 20 and 25 dB higher than that predicted by both models for Soba-Mud and Soba-Jerraif links respectively.

| Link          | Goldhirsh $\text{dB/km}$ | Zain $\text{dB/km}$ | Length km | Goldhirsh Total dB | Zain Total dB |
|---------------|--------------------------|----------------------|-----------|-------------------|---------------|
| SOBA_MUD      | 0.72                     | 0.74                 | 15.22     | 10.8              | 11.24         |
| SOBA_JERRAIF  | 0.72                     | 0.74                 | 12.97     | 9.3               | 9.6           |

Table 3: Comparision between measured and predicted attenuation

| Link          | Goldhirsh $\text{dB}$ | Zain $\text{dB}$ | Measured $\text{dB}$ |
|---------------|------------------------|------------------|-----------------------|
| SOBA_MUD      | 10.8 dB                | 11.24 dB         | 32 dB                 |
| SOBA_JERRAIF  | 9.3 dB                 | 9.6 dB           | 36 dB                 |

6. Conclusion

Dust storms can cause serious attenuation in signal level especially at Ku band and higher frequencies with direct impact on telecommunications system performance. Two operational microwave links at 13 GHz in Sudan were monitored during dust storm and observed more than 30 dB attenuation for about 10 Km lengths. Models proposed by Goldhirsh and Zain were used to predict attenuation on both measurements. It is found that both models underestimate the attenuation measured on both microwave links.
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