Micrometer and Millimeter Wave P-to-P Links Under Dust Storm Effects in Arid Climates

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Abstract—**A dust storm is the main attenuation factor that can disturb receiving radio signals in arid climate condition as in Saudi Arabia. This paper presents a study on the effect of dust storms on the received radio frequency power in a homogenous environment in the city of Riyadh. A number of micrometer and millimeter wave links have been considered along with several measured dust storm data to investigate the dust storm effects. The results showed that dust storm can critically influence the communication link and this effect grows up as the physical distance between the transmitter and the receiver increases. The negative effect of the dust storm apparently appears at high-frequency bands allocated for the next communication generation (5G) which imposes finding solutions to mitigate the effects of this phenomenon.**

Keywords-dust storm; millimeter waves; arid climate; attenuation; receiver sensitivity

I. INTRODUCTION

In the fifth generation (5G) wireless networks, which are expected to be introduced around 2020, there will be some changes, including dramatic changes in the design of different layers for the next generation communication systems. Massive multiple input multiple output (MIMO) systems, filter bank multi-carrier (FBMC) modulation, relaying technologies, and millimeter-wave (mmWave) communications have been considered as some of the strong candidate techniques for the physical layer design of 5G networks [1]. The frequency spectrum represented by mmWave bands is most likely to be used in 5G networks, while mmWave capability can provide a huge amount of spectrum resources. Regardless of the high data rate possibly offered by mmWave, quite a lot of practical difficulties in its use in mobile networks are evident. These difficulties include large path loss, low penetration capability, narrow beam width, fading phenomena due to rain and sand storms, or fading loss due to diffraction, etc. [2-5].

Rain and snow attenuation are predominant factors in regions such as America, Europe and other continental areas, while sand and dust storms are observed in some Arabic countries, such as Saudi Arabia, and arid parts of Australia, and dry states such as Texas and Arizona. Dust storms occur when there are two conditions: the first one is the existence of dry and disjointed soil with no vegetation cover, and the second is high speed wind. The mechanics of the emergence of a dust storm can be explained as follows: When convection currents are created due to the heating of the earth surface, the air above the earth surface becomes warm and then rises up as convection currents. This causes variations in atmospheric pressure and heat, and leads relatively cold winds to be pushed to replace the previous convection currents site, which in turn make dust rise up and carry soil grains up to a level that is proportional to wind power and soil dryness and disintegration. Nowadays, prediction of dust storms has become easy given the availability of metrological data [6]. However, a significant concern in this matter is the fading or signal attenuation caused by the sand storms.

The attenuation factor is varying according to regional meteorological conditions. Authors in [7] focused on dust storm attenuation as a uniform distribution of a specific geometric shape. In this paper, we estimate the attenuation caused by a dust storm, especially on P-to-P terrestrial signals and recommend a solution to avoid power loss due to attenuation over the 5G frequencies. The Saudi capital Riyadh, located on the center of the Saudi desert, is experienced with continuous sand storms. The statistics for the number of sand storms per year in Saudi Arabia during the period 2010-2017 show that the number of sand storms per year ranges between

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83 in 2014 and 212 in 2012 [8]. Among the last observed stand storms, some of them were so strong that the visibility was very low. For example, a huge dust storm engulfed Riyadh city and covered most of its parts on the 10th of March 2009 [9]. It stayed for hours after it started, and visibility highly diminished from kilometers to just very few meters within thirty seconds. In this study, we assume the worst case scenario in which a uniform distribution of dust storm has been considered in order to be in the safe side of received signal prediction.

II. METHOD AND PROPOSED SCENARIO

The wireless point to point (P-to-P) link is proposed to be within an urban area in Riyadh city. The transmitter is placed in Al-Washm at a level of 603.6m above sea level (ASL) while the International King Khalid Airport (IKKA) at 623.7m (ASL) has been considered to be the receiver point, see Figure 1.

Fig. 1. Google map showing IKKA and Al-Washm sites in Riyadh (Google LLC).

The distance between the two points is 34.750km. Riyadh area is considered as an arid area, characterized by dust and sand storms. Thus, the signal potentially undergoes the sand storm effect. This scenario is shown in Figure 2.

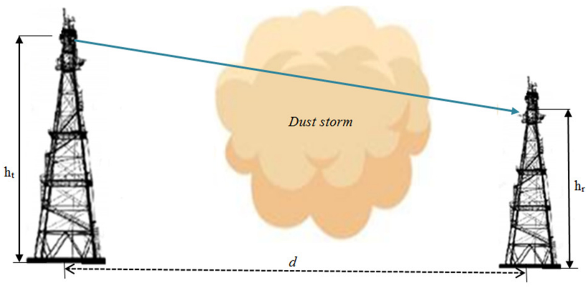

Fig. 2. The proposed scenario (dust storm environment)

The P-to-P has been installed and the system specifications (transmitter and receiver parameters) have been defined with the help of the Radio Mobile tool [4-5] and the channel propagation is assumed to be free space in order to study the worst case scenario. The power is calculated at the receiver under the influence of a homogenous dust storm. Then, the received power has been calculated under the abovementioned effects. The received power and the receiver sensitivity are compered and the results are collected. This method is summarized in the flow chart shown in Figure 3.

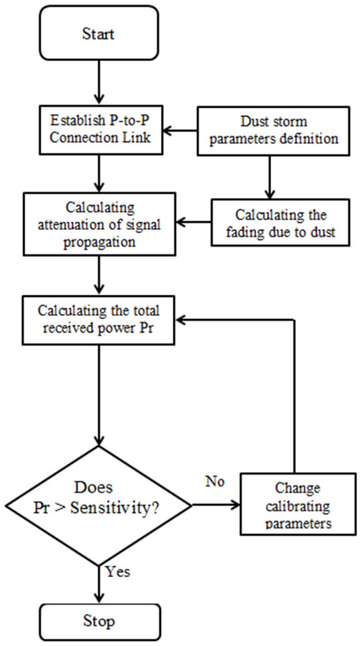

Fig. 3. The flow chart for the proposed method

System installing has been carried out by defining the main specification of the P-to-P system with the help of the Radio Mobile tool, and the propagation channel loss has been computed using Friis' formula. In this formula, we can compute the receiver power, when the following parameters are known: transmitter power P_t, gain of the transmitter and receiver antenna G_t and G_r, respectively, and the channel propagation loss L. Firiis' formula is given by:

$$P_r = \frac{P_t G_t G_r}{L_{fs}} \quad (1)$$

where L_{fs} is the free space loss which mainly depends on the wavelength of the travelling signal λ, and the distance between the transmitter and receiver d. This factor can be defined as:

$$L_{fs} = \frac{4\pi d}{\lambda} = \frac{4\pi d f}{c} \quad (2)$$

where c is the light speed and f is the frequency of the P-to-P link signal. For dust storm effect estimation, due to the fact that when an object (rain drop/particle) is illuminated by a wave, some of the incident power is absorbed and another part is scattered. Thus, the attenuation due to the dust storm can be explained in terms of scattering cross-section of a single particle [10, 11]. The total attenuation, in dB, caused by a dust storm over a link has a length of L can be given as:

$$A = \int_{x=0}^{L} A_d \, dx \quad (3)$$

This solution can be executed by either Rayleigh approximation or Mie solutions [12]. Due to the fact that Rayleigh approximation is based on the assumption that $a_e \ll \lambda$, it is difficult to use it for frequencies bigger than 37GHz [13], while Mie solution has not that limitation and can be used to predict attenuation in various frequency bands with high reliability particularly at higher frequencies. Therefore, this paper proposes the Mie model [14] to be used to estimate the dust attenuation A_d, in dB/km, as a function of the signal wavelength λ, visibility V, radius of dust particles a_e, and dielectric constants of the dust particles for the real and imaginary parts ε' and ε'', respectively.

$$A_d = 94.3C_1\frac{a_e}{V\lambda} + 3721.2C_2\frac{a_e^3}{V\lambda^3} + 23381C_3\frac{{a_e}^4}{V\lambda^4} \quad (4)$$

where C_1, C_2 and C_3 are constants whose values depend on the real (ε') and imaginary (ε'') parts of the dielectric constant of the particles. These constants are:

$$C_1 = \frac{6\varepsilon''}{(\varepsilon'+2)^2+\varepsilon''^2} \quad (5)$$

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

$$C_3 = \frac{4}{3}\left[\frac{(\varepsilon'-1)^2(\varepsilon'+2)+[2(\varepsilon'-1)(\varepsilon'+2)-9]+\varepsilon''^4}{[(\varepsilon'+2)^2+\varepsilon''^2]^2}\right] \quad (7)$$

Visibility V can be expressed in terms of particle density as:

$$V = \frac{5.5\times10^{-4}}{Na_e^2} \quad (8)$$

where N is the dust particle number per volume unit of air in the unit of particles per cubic meter and a_e is the radius of dust particles in meters.

III. SYSTEM SPECIFICATION AND PARAMETERS

The key parameters for the point to point link system are listed in Table I. Various frequencies were used to study the dust storm effects. Receiver sensitivity for each link with different frequency has also different values. In addition, values of dielectric constant vary with each carrier frequency operation.

TABLE I. THE MAIN PARAMETERS OF P TO P LINKS

Parameters	Link 1 [15]	Link 2 [15]	Link 3 [4]
Frequency, GHz	3.9	26	38, 60, 100
Transmitter power, dBm	32	18	43.01
Receiver sensitivity, dBm	-69	-77	-103.02
Transmitter antenna gain, dB	40	40	17
Transmitter height, m	50		
Receiver antenna gain, dB	40	40	2
Receiver height, m	30		
Waveguide loss, dB/m	0.16		
Physical link separation, km	34.725		
Dielectric constants	ε' = 4.56 ε'' = 0.25	ε' = 4.56 ε'' = 0.25	ε' = 3.50 ε'' = 1.64

Measurements of dust storm have been carried out and readings were recorded and are listed in Table II [16]. The measurements have been carried out in Riyadh with the use of passive collectors manufactured according to the ASTM-D1739 [17]. Each collector/bucket has an open topped cylinder with vertical sides and a flat bottom, its minimum diameter is 15cm with a depth of 2-3 times the diameter. The buckets are located at different heights above ground on the receiving tower. The collected dry samples were mixed in a watch-glass and then few drops of distilled water have been added in order to sediment the mixture. The resulted slurry is diluted up to approximately 100ml, and then it was boiled with low pressure to separate any superfluity air bubbles. A system called sedimentation balance was used to record particle weight that fell in the sedimentation fluid in terms of height and time. Finally, Stokes law was used to calculate the particle diameter D.

TABLE II. DUST STORM MEASUREMENT READINGS

Particle average diameter (μm)	Visibility (km)
21.25	0.6
15.3	1
9.8	2
8.2	4

IV. RESULTS AND DISCUSSION

This part of the paper analyzes and discusses the computed received power at IKKA receiver antenna from a transmitter at Al-Washm zone under various dust storm measurements in Riyadh. From the readings in Table II, it can be seen that there are four measurement categories. The first one is with visibility of 0.6km and particle radius of 21.25μm. This case seems the worst case because the signal experienced higher particle radius and lower visibility. Whereas in the rest three cases, the particle radius decreases and visibility increases. Table III shows the corresponding free space loss due to signal propagation for IKKA and Al-Washm sites. In Table IV, the results of sand storm attenuation indicate that the signal fading is directly and inversely proportional to particle radius size and visibility degree. When a dust storm is strong then the visibility degree is low and the signal fading becomes high and vice versa, whereas when the particles radius size is small the signal fading becomes also small.

TABLE III. FREE SPACE PROPAGATION LOSS

	Link 1 (3.9GHz)	Link 2 (26GHz)	Link 3		
			38GHz	60 GHz	100 GHz
L_{fs} (dB)	135.0759	151.5541	154.8503	158.8176	161.3164

TABLE IV. DUST STORM ATTENUATION OF THE LINK PATHS

a_e (μm)	V(km)	A_d (dB/km)				
		Link 1 (3.9GHz)	Link 2 (26GHz)	Link 3		
				38GHz	60GHz	100GHz
21.25	0.6	0.0526	1.1663	3.0939	4.8849	8.1414
15.3	1	0.0226	0.5035	1.3365	2.1103	3.5171
9.8	2	0.0073	0.1632	0.4324	0.6759	1.1264
8.2	4	0.0031	0.0676	0.1788	0.2828	0.4713

The distance versus power received for link1 is depicted in Figure 4 on which power decreases when distance increases. Figure 4 also shows that when the particle radius of dust increases and visibility decreases, then attenuation will increase. In addition, it can be seen that the power received is always greater than the receiver sensitivity which is -69dBm, and this means there is no effect of the dust storm on the receiver performance due to the fact that the link 1 employs a microwave carrier frequency of 3900MHz. The power level is about -27dBm, i.e. there is a margin of 42dB from the receiver sensitivity. On the other hand, if the carrier frequency is increased to 26GHz as shown in Figure 5, there will be not much difference in terms of the receiver performance, but the power margin is decreased to 19dBm. The relation of low visibility and large dust particle size with received power starts to be clear in Figure 5 in which the worst case leads to weaken received power. All four cases in links 1 and 2 are good enough to receive the signal power from transmitter at 34.7km with no critical fading created by the sand storm. In Figure 5, the power received value for all cases is approximately in the range between -58.3 and -57.19dB, which is greater than the sensitivity, so the signal quality is good enough to be received.

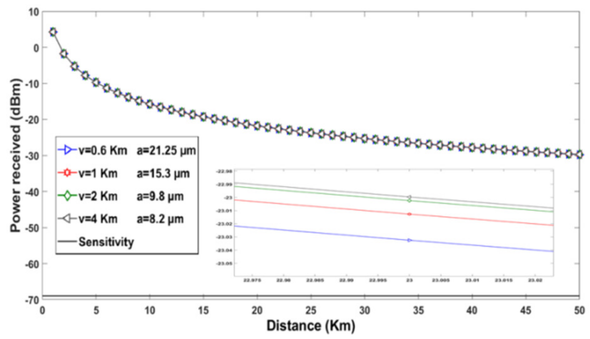

Fig. 4. Physical distance versus received power for link1.

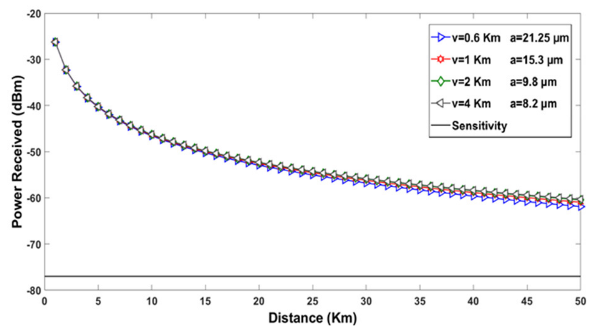

Fig. 5. Physical distance versus received power for link 2.

Regarding link3, we have another three cases with three different frequencies: 38, 60 and 100GHz with a fixed receiver sensitivity of 103.02dBm for all cases. Using 38GHz, at the receiver palace IKKA, the power signal will be received under all four dust storm conditions, as shown in Figure 6. However, at 13km distance after the IKKA (d=48km) the receiver will not be able to sense the transmitted signal especially for the worst dust storm condition of visibility of 0.6km and dust particle size of 21.25μm. The situation will be worse when the link uses 60GHz. In this case, restrictions on using this frequency should be considered spatially when the visibility is lower than 600m and 1000m. For these two conditions (with visibility of 0.6 and 1km), the signal can't be captured by the receiver due to the fact that the power level of the received signal, 107.4 and 103.4dBm respectively, is lower than the receiver sensitivity at IKKA, as shown in Figure 7. The signal at IKKA, for the other two cases (with visibility of 2 and 4km), will not be affected because the power received is -101.3 and -100.8dBm for visibility of 2 and 4km, respectively. However, the signal will deteriorate after about 10km from IKKA (i.e. at a distance greater than 44km from the transmitter). For the link3 with carrier frequency of 100GHz as shown in Figure 8, the signal will not be received for all visibility cases due to high dust attenuation. The power level at IKKA is about -117.2, -109.7, -106.6 and -105.8dBm for visibility of 0.6, 1, 2 and 4km, in the same order. The maximum distance between the transmitter and the receiver with sensitivity of -103.02dBm is 15.5, 20, 24 and 27km for visibility of 0.6, 1, 2 and 4km, respectively.

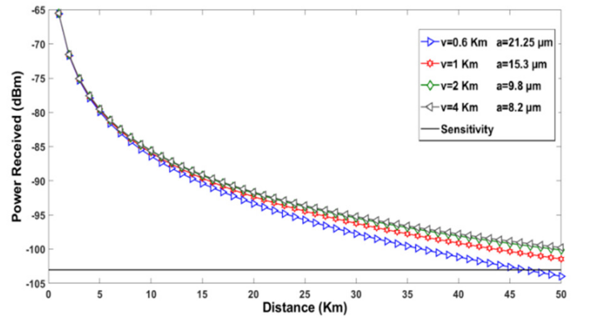

Fig. 6. The physical distance versus power received for link3 at 38GHz.

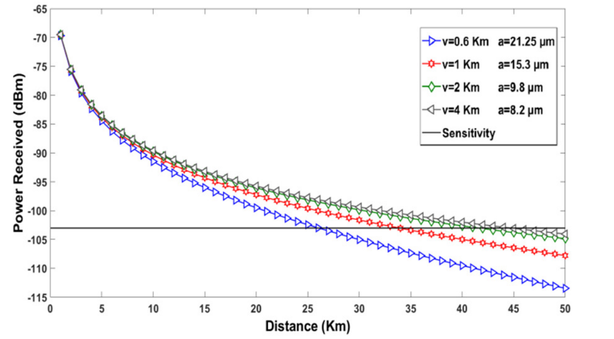

Fig. 7. The physical distance versus power received for link3 at 60GHz.

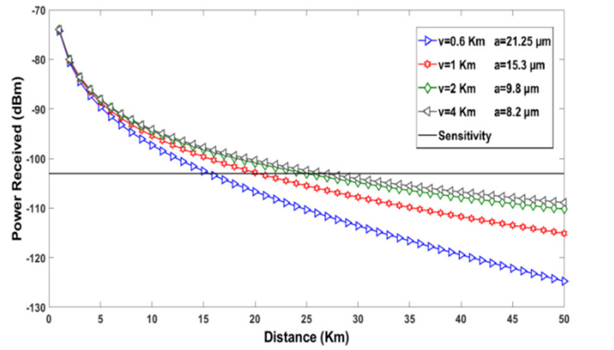

Fig. 8. The physical distance versus power received for link3 at 100GHz.

Therefore, as a solution, the use of an RF relay system every 15.5, 20, 24 and 27km for all abovementioned visibility conditions of the same order is suggested. Also, the transmitter power can be increased during dust storms to compensate the attenuation. In addition, data rate reduction, adjusting modulation and coding techniques are also mitigation solutions that can be used to mitigate the problem.

V. CONCLUSION

This paper presents a study of the dust storm effect on communication channel performance in the arid area of

Riyadh, Saudi Arabia. Measured dust storm data have been employed to investigate this factor. It was shown that severe dust storm may result to radio link interruption due to dust attenuation, especially in high frequency, large communication link, low visibility and large particle size conditions. These situations need technical mitigation schemes such as using an RF relay system, power control and/or adaptive modulation.

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