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Analysis of Rain Effects on Free Space Optics Based on Data Measured in the Libyan Climate

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***Abstract*—In this paper, the effect of rain on Free Space Optical link (FSO) performance based on data measured and recorded in the Libyan National Meteorological Center (LNMC) is investigated. A modified FSO link equation based on CARBONNEAU empirical model is used to provide a direct relation between the rain fall rate and the maximum allowable FSO link length. The effect of the heaviest case of rainfall occurred in Libya for the FSO is simulated, and the maximum allowable link length is obtained.**

***Index Terms*—Free space optics, optical link measurements, optical link analysis, optical link rain effects.**

I. INTRODUCTION

Free Space Optical communication is a line of sight technology that transmits information by laser light through an atmospheric channel. Relying on infrared light, these communication systems are immune to electromagnetic interference (EMI), jamming, or wiretapping. And they operate at frequency bands (around 300 THz) where the spectrum is unlicensed [1]. The availability of FSO is the main concern since this technology uses free space as a transmission medium, the main challenge is the weather condition which directly affects the performance by attenuating the signal either through scattering, absorption, or scintillation.

In Libya, the weather throughout the years has not been snowy or foggy except for some regions in the mountains. Here, in this paper a modified rain equation along with the data measured and recorded in the Libyan National Meteorological Center (LNMC) are used in the analysis and simulation of the FSO link and only the rain effect is considered [2].

II. LIGHT PROPAGATION AND ATMOSPHERIC ATTENUATION (THEORETICAL BACKGROUND)

Free Space Optic (FSO) links involve the transmission, absorption and scattering of the light by the Earth's atmosphere. The atmosphere interacts with light due to the atmosphere composition which, under normal conditions, consists of a variety of different molecular species and small suspended particles called aerosols. This interaction produces a wide variety of optical phenomena: selective absorption attenuation, scattering and scintillations.

The transmission of Light in the atmosphere is described by the Beer Lambert Law [3]:

$$T(\lambda, L) = \frac{P(\lambda, L)}{P(\lambda, 0)} = \exp[-\gamma(\lambda)\,\mathrm{L}] \tag{1}$$

where:

T (λ, L) is the total transmittance of the atmosphere at wavelength λ.

P (λ, L) is the signal power at distance, L from the transmitter.

P (λ, 0) is the emitted signal power.

γ (λ) is the attenuation coefficient per unit length. The attenuation coefficient is composed of absorption and scattering terms. Generally it is the sum of the following terms:

$$\gamma(\lambda) = \alpha_m(\lambda) + \alpha_a(\lambda) + \beta_m(\lambda) + \beta_a(\lambda) \tag{2}$$

Where: α_m and α_a are molecular and aerosol scattering coefficients respectively and β_m, β_a are the molecular and the aerosol absorption coefficients respectively.

Molecular absorption attenuation results from an interaction between the radiation and atoms and molecules of the medium (N2, O2, H2, H2O, CO2, O3, Ar, etc.). The absorption coefficient depends on the type of gas molecules and on their concentration. Molecular absorption is a selective phenomenon which results in the spectral transmission of the atmosphere presenting transparent zones, called atmospheric transmission windows, and opaque zones, called atmospheric blocking windows [3].

Atmospheric scattering results from the interaction of a part of the light with the atoms and/or the molecules in the propagation medium. It causes an angular redistribution of this part of the radiation with or without modification of the wavelength.

Aerosols scattering (also known as Mie Scattering) occurs when the particle size are of the same order of magnitude as the wavelength of the transmitted wave. In optics it is mainly due to mist and fog [3].

In the region used by FSO systems attenuation coefficient is only approximated by the scattering coefficient because the range of wavelengths used by FSO falls inside the transmission window [3].

In this paper, only the scattering coefficient due to rain and its effect on the FSO performance will be analyzed.

Attenuation is a function of frequency but also of the visibility related to the particle size distribution. This phenomenon constitutes the most restrictive factor to the deployment of Free Space Optical systems at long distance. The visibility is a concept defined for the needs of the

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meteorology. It characterizes the transparency of the atmosphere estimated by a human observer. It is measured by the Runway Visual Range (RVR), distance that a parallel luminous ray's beam must travel through the atmosphere until its intensity drops to 0.05 times its original value. It is measured using a transmissometer or a diffusiometer. In this paper the attenuation due to rain effect is not calculated by the empirical formula that depends on the visibility range (Kim's model) due to lack of equipment needed to find the visibility. It is calculated by CARBONNEAU relation which is a function of rainfall rate (mm/hour) [1] and [4].

III. FSO Equation and The Empirical Rain Attenuation Model

FSO performance is described by the following equation:

$$P_{RX} = P_{TX} + L_{g.} - L_{atm.} - L_{mp.} - L_{opt} \quad (3)$$

where :

$P_{RX.}$: Received power.
P_{TX}: Transmitted power.
$Lg.$: geometric loss.
L_{atm}. : Atmospheric loss.
L_{mp}. : Miss pointing loss.
L_{opt}. : Optical loss.

Geometric Loss is caused by beam divergence, due to the spreading of the transmitted beam light between the transmitter and the receiver and defined as [5]:

$$Lg = 10 \text{ Log}\left[\frac{D_R}{D_T + d * \theta}\right]^2 \quad (4)$$

where:

D_R, D_T are the Receiver's and the transmitter's diameters respectively.

d is the distance in Km. and θ is the beam divergence in mrad.

L_{atm}., is the atmospheric loss due to rain attenuation and it's defined by two empirical models; KIMS model and Carbonneau's model.

- KIMS model:

Attenuation coefficient due to rain is wavelength independent and only depends on the visibility and it is described by the following equation [6]:

$$\sigma_{rain} = \frac{2.9}{v} \quad \text{(1/Km)} \quad (5)$$

$$L_{atm} = 10 \text{ Log} (\exp(-\sigma_{rain} \times d)) \quad \text{(dB)} \quad (6)$$

where V is the visibility.

As mentioned, in this paper we will not use this model because of its dependence on the visibility which cannot be measured.

- Carbonneau's model:

This empirical model depends on the rainfall rate (mm/hour) and its accuracy depends on the accuracy of the rainfall rate measurements [3]. The rain attenuation model is given by:

$$A_{attenuation} = 1.076 \times R^{0.67} \text{ (dB/Km)} \quad (7)$$

$$L_{atm} = A_{attenuation} \times d \quad \text{(dB)} \quad (8)$$

where R is the rainfall rate in (mm/hour).

This empirical method is based on correlation between observed attenuation distribution and corresponding observed rain-rate distribution measured at 1 minute integration time. The constants in this relation are constants found by CARBONEAU after taking measurements and data in non-tropical region (i.e. France) [4]. The attenuation due to CARBONEAU's relation varies for different rainfall rates as Fig. 1:

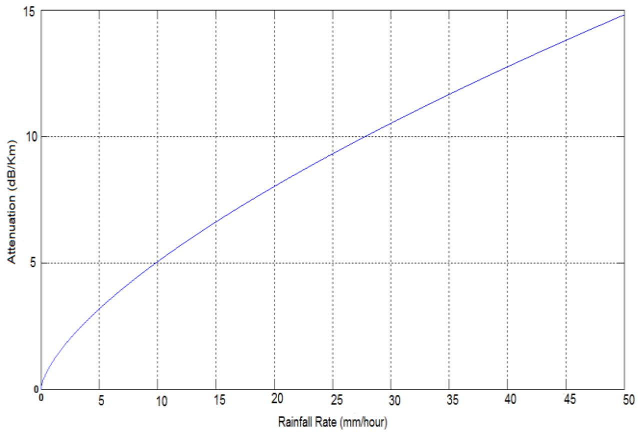

Fig. 1. Attenuation (dB/km) vs Rainfall rate (mm/hr).

The miss pointing loss is caused by the imperfect alignment of the transmitter with the receiver (typically 3db) whereas optical losses are the coupling and the insertion losses that occur when the optical signal is transmitted/received into/from a lens or reflected off a mirror(typically 9db) [7].

The FSO link equation is stated in a more convenient and modified form:

$$Pr = Pt + 10 \text{ Log}\left[\frac{D_R}{D_T + d \times \theta}\right]^2 - 12 \text{ dB} - [1.076 \times R^{0.67} \times d] \quad (9)$$

Now, taking the specification of an FSO transceiver that is specified for 2km, and another one specified for 0.8km distance with the following data and assumptions (worst case assumptions) [8]:

For the 2km Transceiver,
Pt = 16.98dBm
Pr = minimum sensitivity + 3 dB (Margin) = −31dBm
For the 0.8km Transceiver,
Pt = 14.47dBm
Pr = minimum sensitivity + 3 dB (Margin) = −34dBm
D_R= 0.4 m, D_T = 0.16 m and θ = 3mrad are for the two transceivers.

Using all the data recorded in the (LNMC) of the rainfall rate through about 60 years (1946-2000) to find the resulted ranges (in km) and wither or not Rain affects the FSO performance in Libya [2] and [9]. The seasonal percentage of precipitations of rainfall in the above mentioned 60 years in fourteen Libyan cities are listed in Table I.

TABLE I: SEASONAL PERCENTAGE OF PRECIPITATIONS IN LIBYA FROM YEAR 1946 TO 2000 [9]

Station	Annual total precipitation (mm)	Winter (%) (Dec.--Feb.)	Autumn (%) (Sep.Nov.)	Spring (%) (Mar.-May)	Summer(%) (Jun.--Aug.)
Agedabia	145	68.9	18.7	12.4	0.0
Benina	269	64.5	21.7	13.6	0.2
Derna	269	57.3	27.3	14.4	1.0
El-Kufra	10	37.3	14.2	38.6	9.5
Ghadames	32	43.6	18.8	34.8	2.8
Jaghboub	16	61.3	10.7	27.4	0.6
Jalo	9	47.9	22.3	29.8	0.0
Misurata	274	53.1	34.1	12.2	0.6
Nalut	149	34.4	26.9	37.1	1.6
Sebha	9	40.9	29.8	25.3	4.0
Shahat	559	57.9	23.8	17.6	0.7
Sirt	187	54.8	32.9	11.9	0.4
Tripoli	336	51.4	33.9	14.2	0.5
Zuara	239	43.3	40.8	15.4	0.5

Considering the winter season only with a rainy weather condition of about one month out of three months and 4 hours a day, the resulted data of this case are tabulated in Table II.

TABLE II: RESULTED RAIN FULL RATE (MM/HOUR) IN EACH CITY TAKING A CASE OF 30 RAINY DAYS OUT OF 90 DAYS OF 4 HOURS / DAY

Station	Annual total precipitation (mm)	Winter (%) (Dec.Feb.)	Rainfall rate mm/3month	Rainfall rate mm/hour
Agedabia	145	68.9	99.91	0.8
Benina	269	64.5	173.5	1.445
Derna	269	57.3	154.13	1.28
El-Kufra	10	37.3	3.77	0.0314
Ghadames	32	43.6	13.9	0.116
Jaghboub	16	61.3	9.81	0.0817
Jalo	9	47.9	4.3	0.0359
Misrurata	274	53.1	145.49	1.21
Nalut	149	34.4	51.25	0.427
Sebha	9	40.9	3.68	0.0306
Shahat	559	57.9	323.6	2.69
Sirt	187	54.8	102.4	0.85
Tripoli	336	51.4	172.74	1.439
Zuara	239	43.3	103.48	0.86

To find the maximum distance allowed for the FSO link to work properly (i.e. Received power is above the minimum sensitivity and no fading exists), we use the calculated R for each city in equation (9). The resulted Maximum distances allowed are in Table III.

TABLE III: THE RESULTED THE DISTANCE IN KM FOR THE TWO TRANSCEIVERS

Station	Rainfall rate mm/hour	Distance(Km) 2Km Transceivers	Distance(Km) 0.8Km Transceivers
Agedabia	0.8	4.91	5.29
Benina	1.445	4.235	4.53
Derna	1.28	4.374	4.69
El-Kufra	0.0314	7.6	8.44
Ghadames	0.116	6.82	7.5
Jaghboub	0.0817	7.07	7.81
Jalo	0.0359	7.53	6.3
Misrurata	1.21	4.44	4.76
Nalut	0.427	5.612	6.09
Sebha	0.0306	7.6	8.45
Shahat	2.69	3.53	3.76
Sirt	0.85	4.84	5.22
Tripoli	1.439	4.24	4.54
Zuara	0.86	4.83	5.22

The resulted distances for the two transceivers are shown in Fig. 2.

From the results obtained, we can see that the transceivers work properly and there is no faded signal (i.e. Pr > Sensitivity), which means that Libya's rainy weather does not affect the FSO performance. What is worth mentioning is that these results do not mean that these distances can be achieved with no error because each transceiver has a divergence angle specified only for the mentioned range and it will change after the specified range for each transceiver is exceeded. However, we also investigate the effect of the maximum recorded rainfall in a day in Libya with 150mm [10].

Considering precipitation of an average of 10 hours in that day (i.e. 15 mm/hour) and Using equation (9) with a 2km transceiver we can find out that the maximum distance allowed for this worst case is d=1.91km, which means that even in this worst condition, the FSO system will still work properly within this range.

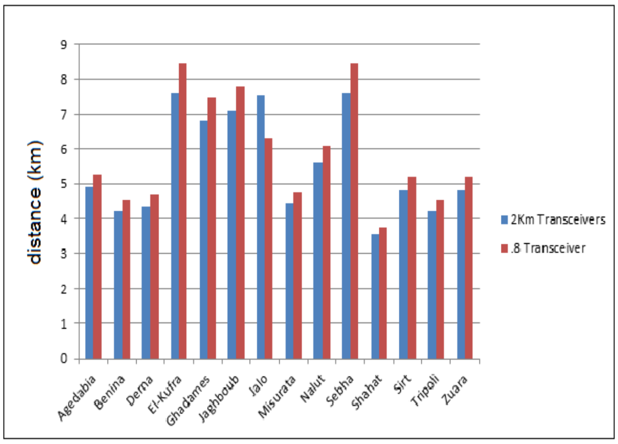

Fig. 2. Cities in Libya with maximum distance allowed for both transceivers.

It is simulated using Optisystem v.7 and the obtained results ensure our calculations (Pr> Sensitivity).

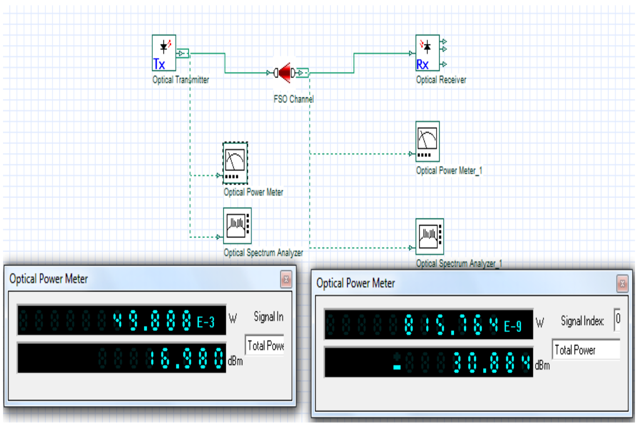

Fig. 3. Simulation of the heaviest rainfall case recorded with 150mm a day.

IV. CONCLUSION

Based on the collected data from the LNMC and using the modified equation that is based on CARBONNEAU empirical model, simulation of the effect of rain on the FSO link is performed. This study shows that Rain in Libya does not have a significant impact on FSO performance. The results of the study indicated that this analysis is general and could be applied to many other countries.

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