ANALYSIS OF FREE SPACE OPTICAL LINK IN TURBULENT ATMOSPHERE AND FINDING OPTIMUM SOLUTIONS FOR BAD WEATHER

J component project report

ECE4005-OPTICAL COMMUNICATION AND NETWORKS

Submitted By:

DEMADA CHETAN REDDY-17BIS0030

K.RAKESH REDDY-17BIS0069

D.LOHITH-17BIS0089

Under the guidance of,

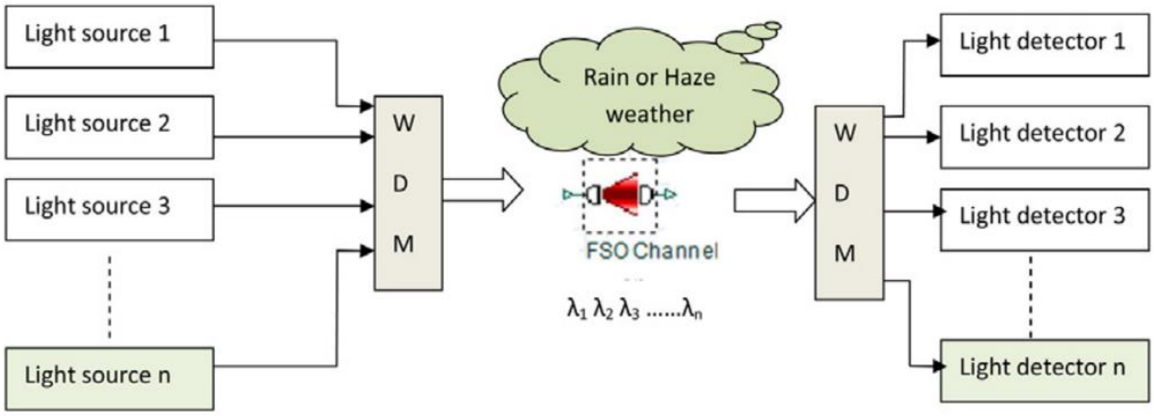
Prof. Dr. ILVARASAN T

ABSTRACT:

Free Space Optics Systems (FSO) is one of the most effective solutions, especially for atmospheric turbulence due to the weather and environment structure. Free space optics system suffers from various limitations. A well-known disadvantage of FSO is its sensitivity on local weather conditions-primarily to haze and rain, resulting in substantial loss of optical signal power over the communication path. The main objective of this article is to evaluate the quality of data transmission using Wavelength Division Multiplexing (WDM) with highlighting several factors that will affect the quality of data transmission. The results of these analyses are to develop a system of quality-free space optics for a high data rate transmission. From the result analysis, FSO wavelength with 1550 nm produces less effect in atmospheric attenuation. Short link range between the transmitter and receiver can optimize the FSO system transmission parameters or components. Based on the analysis, it is recommended to develop an FSO system of 2.5 Gbps with 1550 nm wavelength and link range up to 150 km at the clear weather condition of bit-error-rate (BER) 10^{-9}.

INTRODUCTION:-

Free space optics based on WDM system suffers from various limitations, especially atmospheric turbulence due to the weather and environment structure . Atmospheric attenuation of FSO system is typically dominated by haze and fog, but is also dependent upon rain and dust. The total attenuation is a combination of atmospheric attenuation and geometric losses. Scattering produced by atmospheric particles can be considered as a form of dispersion of the energy that makes the signal divert from its original target. Geometrical scattering is the result of raindrops and snow that are made of larger molecules having an impact similar to Raleigh scattering. Turbulence is the random fluctuation in the refraction index of air produced by differential heating and has the effect of defocusing the beam, producing intensity fluctuations in the received signal (scintillation), and contributing to the spreading of the transmitted beam. Turbulence is partially compensated by tracking and adaptive optics techniques, and it has a greater impact on higher frequencies within the near infrared sub-band (1550 nm is therefore, less affected) .



OPTIMUM SYSTEM DESIGN:

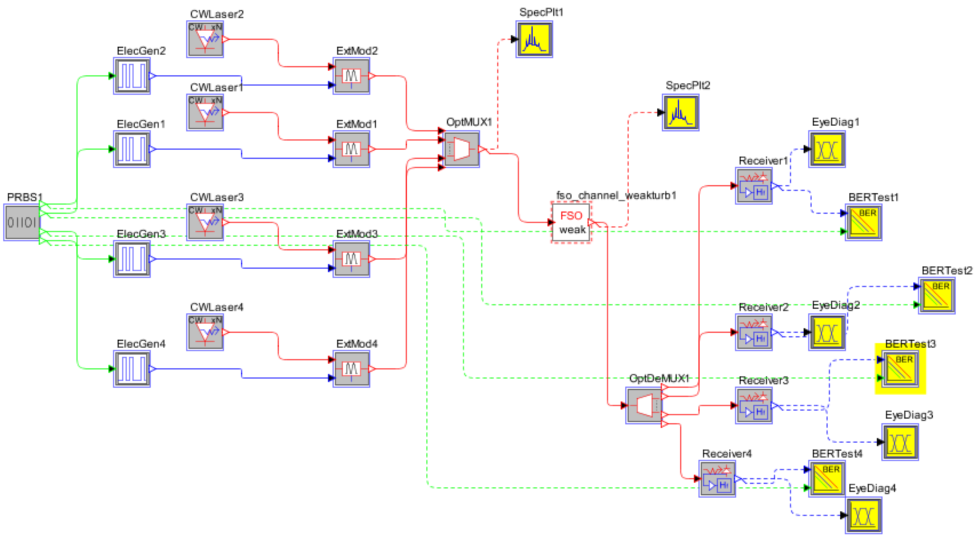
1)WDM DESIGN:

The block diagram of a typical FSO system is shown in the above figure. This figure shows the basic concept and devices that have been used in designing the unidirectional WDM system. There are Pseudo-Random Bit Generator, NRZ Pulse Generator, CW Laser, Mach-Zehnder Modulator at transmission part.The impact on system design parameters are illustrated in the representative characteristic and data observation given in Table 1; with proper parameters, FSO based on WDM system can be optimized to achieve a maximum link range of operation. The quality of the received signal is greatly depends on the conditions of the free space channel and the WDM system design. In order to suppress the beam diffraction that occurs naturally with propagation, an optical signal is then sent through an optical fiber to a collimating optical system.

WDM PARAMETERS:

DATA RATE	2.5Gbps
Power	-10dBm
Link Range	1000m

Channel spacing	20nm



2)RAIN:

Rain intensity factor is capable of attenuating laser power and cause system under performance in a free space optical (FSO) communication system. In general, weather and installation characteristics are the key factors that could possibly reduce visibility and also impair the FSO performance. The derived mathematical model will then be analyzed and correlated with the local rain data . This work will bepresentedas follows: anumericalmodel based on the Beer's law and Stroke law. The loss or attenuation fromatmospheric effects can be calculated using various models available in propagation literatures. The attenuation of the laser power in the atmosphere is described by Beer's law :

$$T(R) = P(R) / P(0) = e^{-\beta R}$$

Parameters:

FSO link parameters, (a) constant value; (b) rainfall rate.

A)	
Gravitational constant	980 cm/s2

Water density	1 g/cm2
Viscosity of air	1.8 × 10−4 (g/cm)s
Droplet, a	0.001–0.1 cm
Wavelength	1550 nm
Qscat	2

Type	**mm/h**	**cm/s**
Light	**26**	**7.22E-3**
Medium	**40**	**1.11E-3**
Heavy	**80**	**2.22E-3**

where R is the link range in meters, (R) is the transmittance at a range R (km), P(R) is the laser power at range R. P(0) is the laser power at the source (Watt), and ˇ is the scattering coefficient (km−1). The scattering particles are large enough that the angular distribution of scattered radiation can be described by geometric optics. Raindrops, snow,hail, cloud droplets, andheavy fogs will geometrically scatter laser bit's signals. The scattering is called non-selective because there is no dependence of the attenuation coefficient on laser wavelength. The scattering coefficient can be calculated using Stroke law.

$$\beta_{\text{rain scat}} = \pi a^2 Na\, Q_{\text{scat}} \left(\frac{a}{\lambda}\right)$$

where a = radius of raindrop (0.001–0.1 cm), Na = rain drop distribution, Qscat = scattering efficiency, and λ = wavelength. The raindrop distribution, Na can be calculated.

$$Na = \frac{Za}{4/3(\pi a^3)Va}.$$

Za is rainfall rate (cm/s), a = droplet radius and Va = limit speed precipitation. Limiting speed of raindrop is also given as

$$Va = \frac{2a^2 \rho g}{9\eta}.$$

is water density (g/cm2), g is gravitational constant and η is viscosity of air.

3)HAZLE FOG:

The FSO system performance depends on the attenuation value at different visibility level. Because haze results in more particles stay longer in atmosphere compared to rain, it presents more serious degradation on FSO performance. In normal practice of FSO, evaluation of FSO performance is conducted by testing the actual system at the site. This process requires the FSO hardware to be installed temporarily at site to acquire the system performance. If the attenuation performance of the system is satisfactory, the system is then permanently installed and commissioned. On the other hand, ifthe system shows poor performance, necessary adjustment of system parameters and/or hardware is needed. In this project, a more proactive method to forecast the system performance is proposed without having to physically install the hardware . The alternative method is by using mathematical analysis by using Kim & Kruse Model .

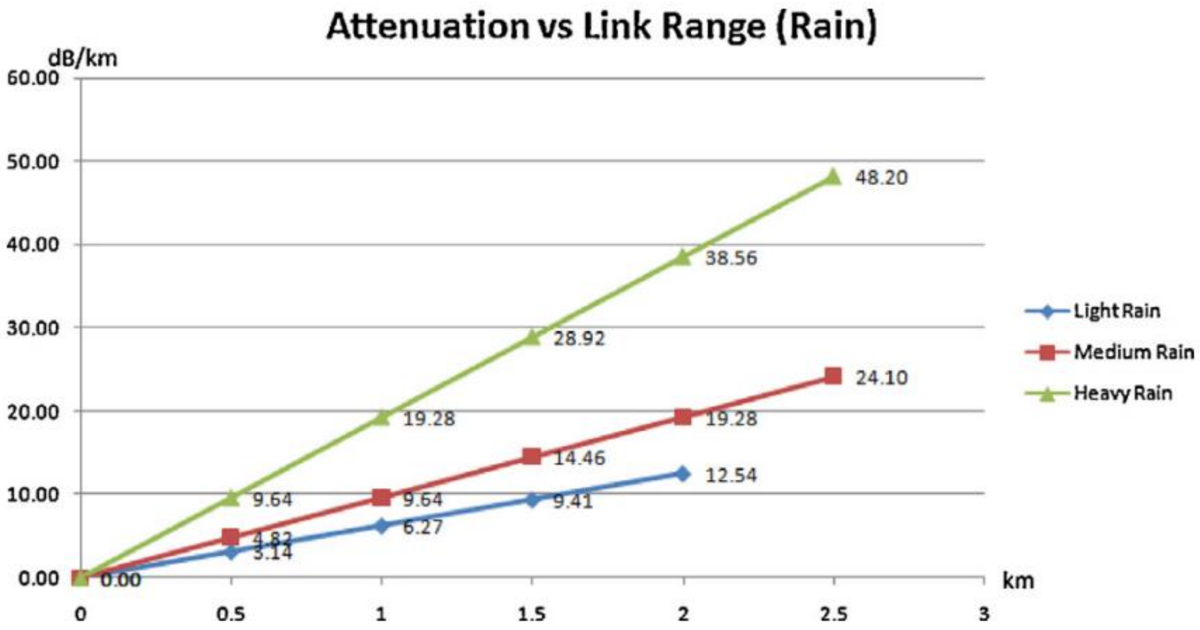
$$\beta = \frac{3.91}{V}\left(\frac{\lambda}{550\,\mathrm{nm}}\right)^{-q}.$$

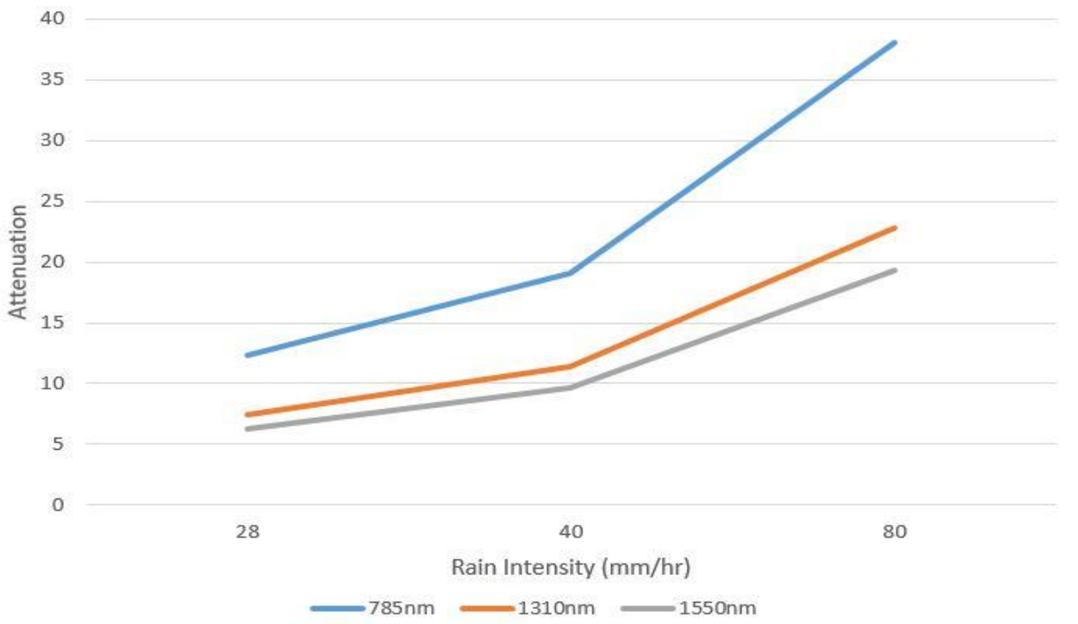
where, β = haze attenuation, V = visibility in kilometers, λ= wavelength in nanometers and q = the size distribution of the scattering particles {1.3 for average visibility (6 km < V < 50 km) and 0.585V1/3 for low visibility (V < 6 km)}. In other references, it adds as 1.6 for very high visibility (V > 50 km) . The International Visibility Codes for Weather Conditions and Precipitation. The term geometrical loss refers to the losses that occur due to the divergence of the optical beam.

SIMULATION RESULTS

Rain analysis

In the analysis, it was divided by two major key, which is to compare the performance of some relevant attenuation and the attenuation along the rainy condition for the best wavelength. In this case 785 nm, 1310 nm and 1550 nm wavelengths are studied. According to calculated result, Fig. 2 showed that 1550 nm is the best choice with the lowest attenuation in dB/km for every type of rainy condition. Light rain is recorded as 6.27 dB/km, 9.64 dB/km for medium rain while 19.28 dB/km for heavy rain (refer to Fig. 3). However, system performance will be improved by using 1550 nm, while the other wavelengths show the higher attenuation compare to this 1550 nm wavelength.





Weather Condition	Bitrate	Power(dB)	Amp Gain	BER
Light Rain(5.77dB/km)	155Mbps	9	21dB	1.08e-10
Medium Rain(8.88dB/km)	155Mbps	22	25dB	2.24e-8
Heavy Rain(17.7dB/km)	155Mbps	25	30	1.8E-7

OPTIMUM CONDITIONS DURING RAIN ARE

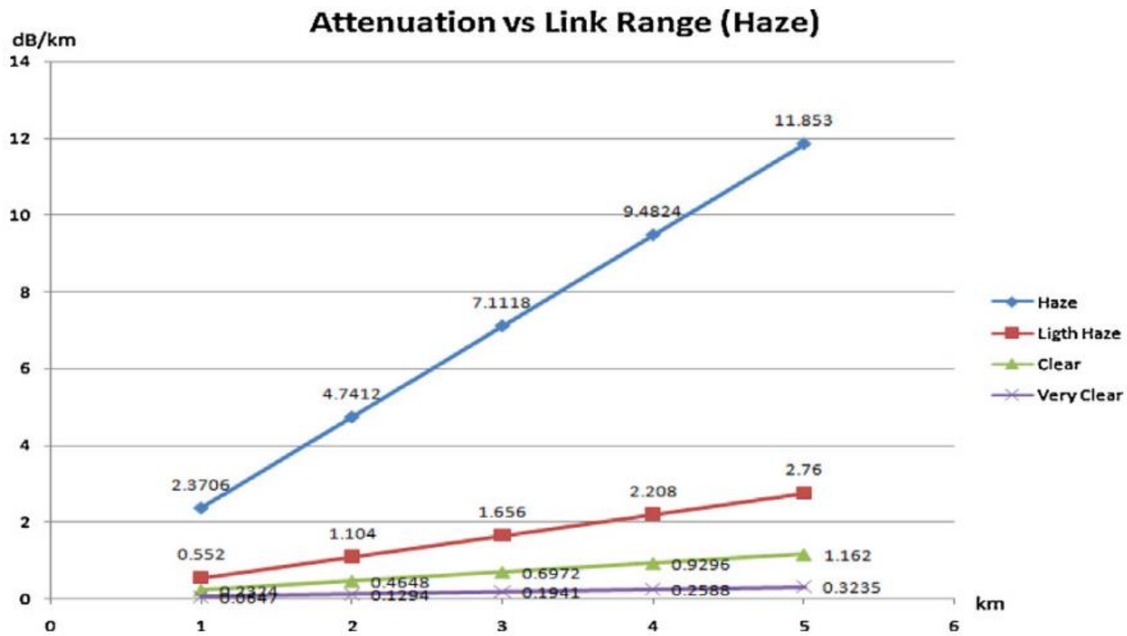
Weather conditioon	ATT(dB/km)	Laser Power(dBm)	Area	BitRate	Link Range
Light Rain	5.77	20	30	155-600Mbps	1km-6.5km
Medium Rain	8.88	22	30	155-600Mbps	1km-5km
Heavy Rain	17.7	25	30	155-600Mbps	1km-3km

Haze analysis:

To quantitatively assess which wavelengths, visibility range, attenuation presented in haze had more severe impact on the FSO performance.

	Bitrate	Power(dBm)	Ampllifier gain	BER
Clear weather(0.065)	2.5Gbps	-1	15	2.03e-9
Light Haze(0.855)	2.5Gbps	4	20	6.26e-9
Heavy Haze(3.08)	1Gbps	21.5	25	1.016e-9

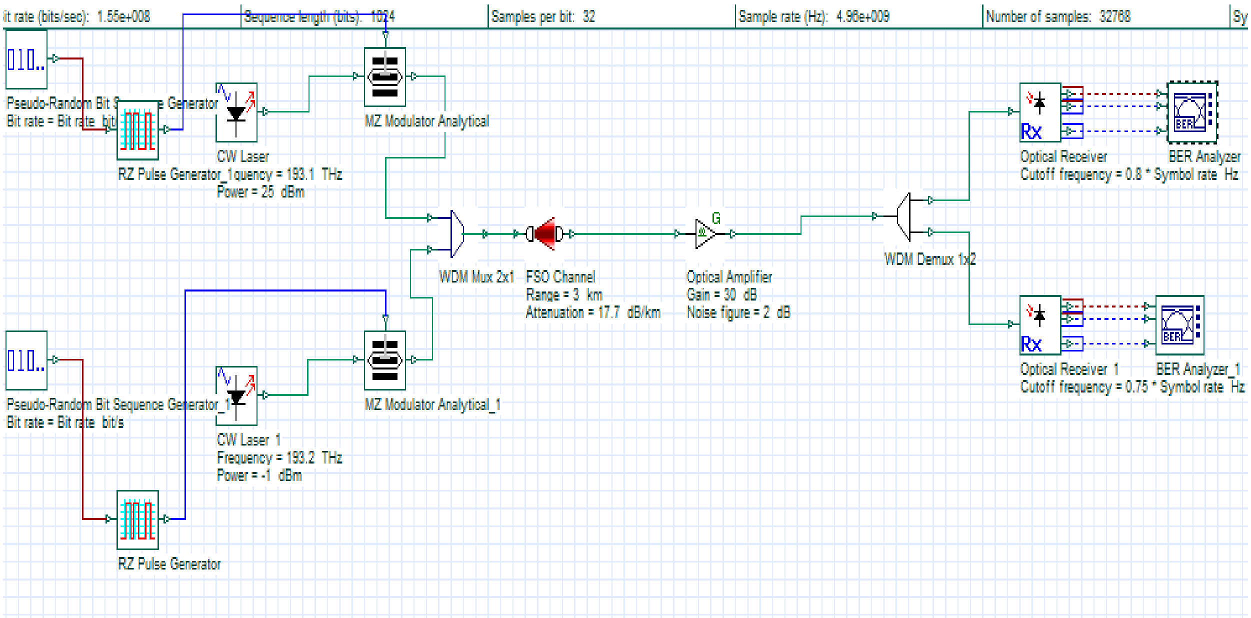
Therefore, by comparing the performance of some relevant attenuation and then evaluated the attenuation along the haze condition for the best wavelength. In haze analysis, the clear weather condition is included in this analysis. By referring for the very clear weather conditions is not showing many precipices of each wavelength. In clear condition also describing the minimize precipice which is 0.23 dB/km for 1550 nm, 0.28 dB/km for 1310 nm and 0.56 dB/km for 785 nm. However, it was start give a high gap when in haze condition. Therefore, the results show that the attenuation is high at 785 nm wavelength. Hence, the best choice to face the haze attenuation is to use a 1550 nm wavelength.

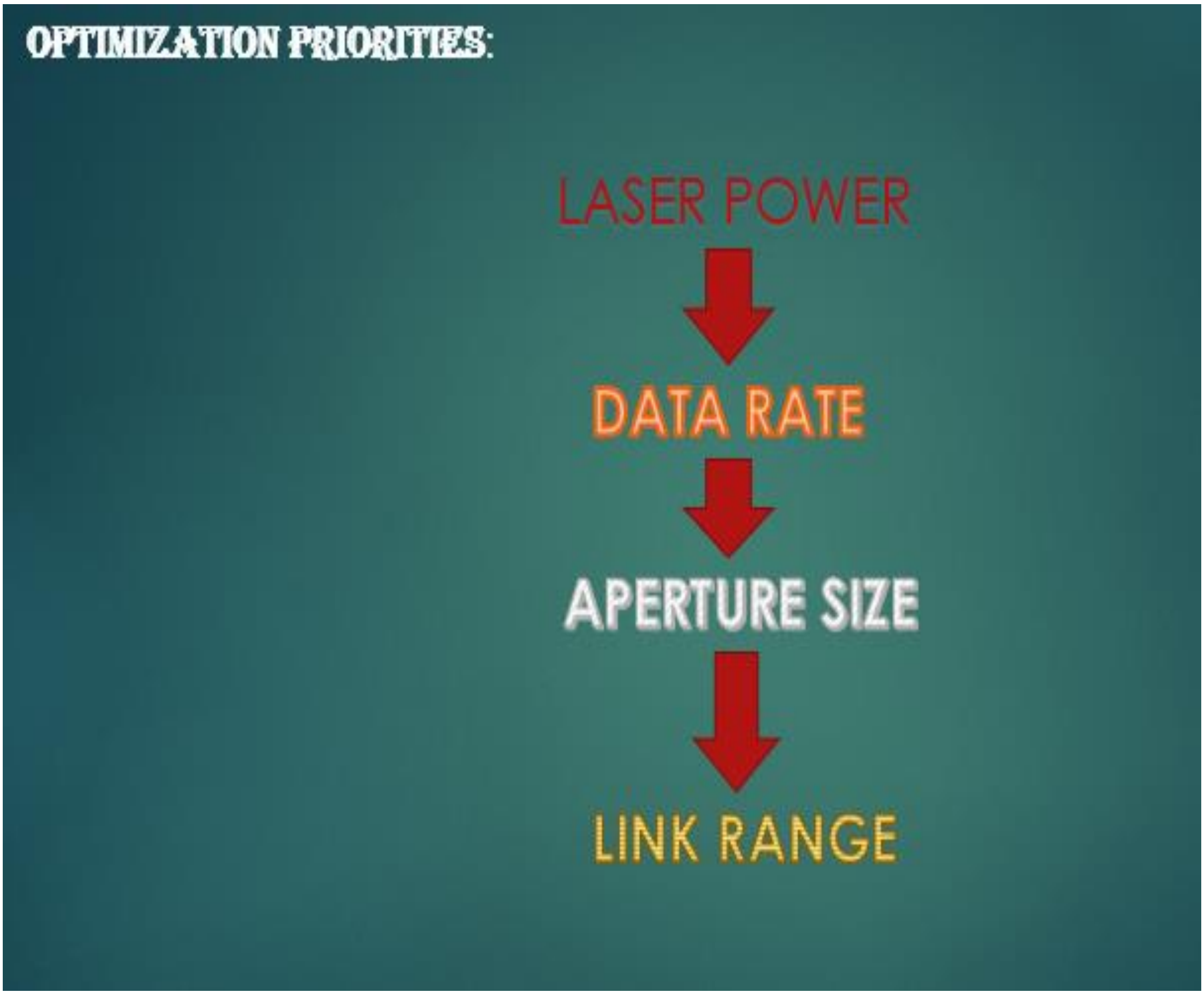


OPTIMUM CONDITIONS DURING HAZE:

Weather condition	**ATT(dB/km)**	**Laser Power(dBm)**	**Area**	**BitRate**	**Link Range**
Clear weather	0.065	-10	30	1-2.5Gbps	1km-10km
Light Haze	0.855	1-5	30	1-2.5Gbps	1km-8km
Heavy Haze	3.08	20-25	30	155-800Mbps	1km-5km

CIRCUIT DIAGRAM:




OPTIMIZATION PRIORITIES:
LASER POWER
DATA RATE
APERTURE SIZE
LINK RANGE

CALCULATING ATMOSPHERIC ATTENUATION:

HAZE:

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Hase

Heavy haze (3.5 km)

$$\beta = \frac{3.91}{V}$$

$$q = \frac{0.585\ V}{3} = 0.6825$$

$$\beta = \frac{3.91}{V}\left(\frac{\lambda}{550\ nm}\right)^{-q}$$

$$= \frac{3.95}{3.5}\left(\frac{1550}{550}\right)^{-0.6825} \times 4.303$$

$$= 2.392\ dB/km$$

light haze ($V = 8$ km)

$$q = 1.3$$

$$\beta = \frac{3.91}{8}\left(\frac{\lambda}{550nm}\right)^{-1.3}$$

$$= \frac{3.91}{8}\left(\frac{1550}{550}\right)^{-1.3} \times 4.303$$

$$\beta = 0.55\ dB/km$$

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clear (18 km)

$q = 1.3$

$$\beta = \frac{3.91}{V}\left(\frac{\lambda}{550\,nm}\right)^{-1.3}$$

$$= \frac{3.91}{18}\left(\frac{1550}{550}\right)^{-1.3} \times 4.303$$

$$\beta = 0.245\ dB/km$$

Very clear (50 km)

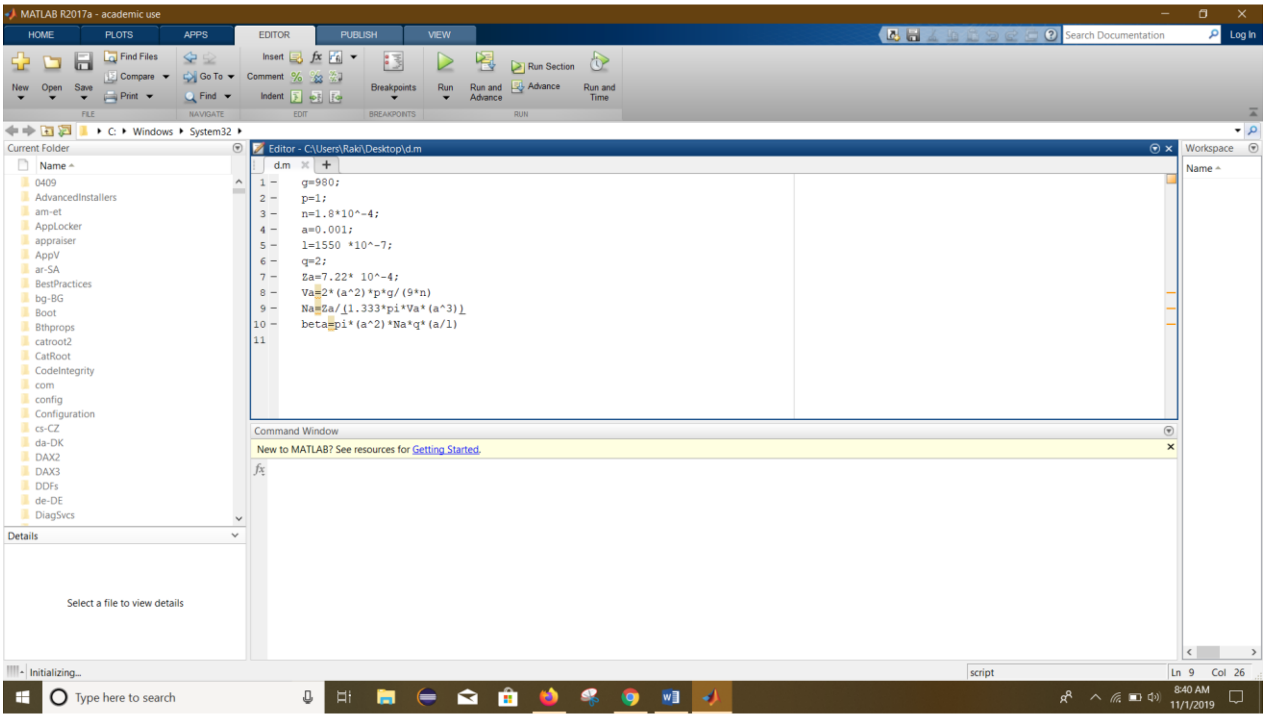
$q = 1.6$

$$\beta = \frac{3.91}{V}\left(\frac{\lambda}{550\,nm}\right)^{-q}$$

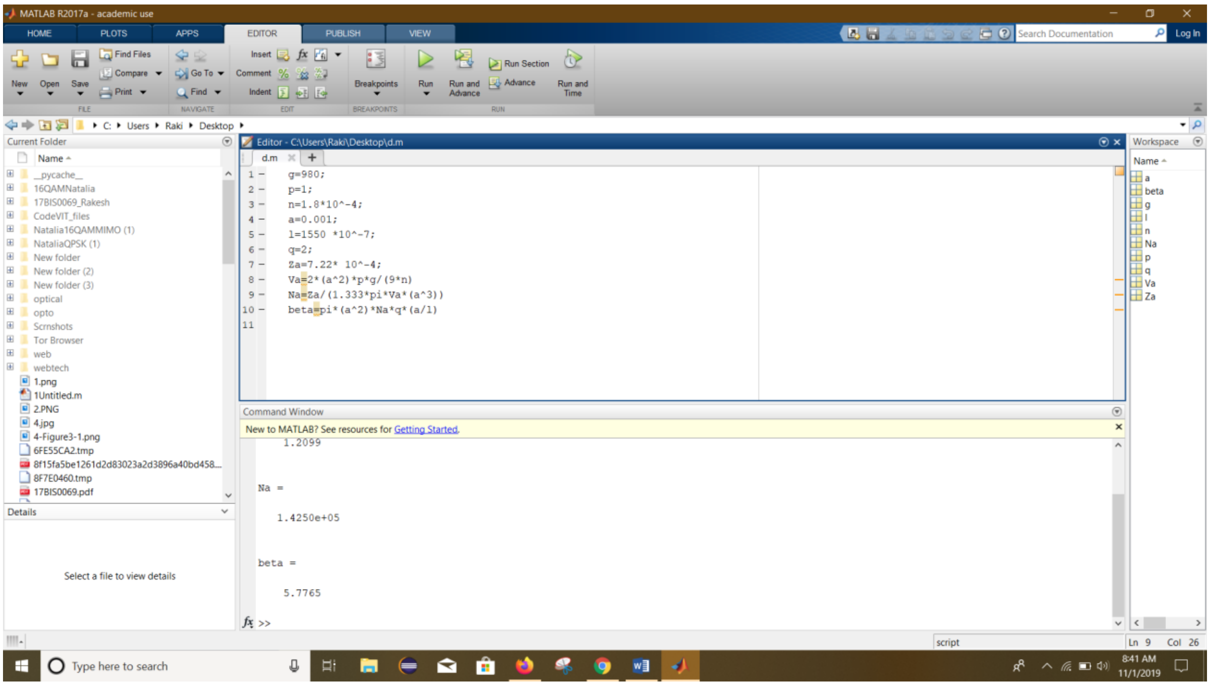
$$= \frac{3.91}{50}\left(\frac{1550}{550}\right)^{-1.6} \times 4.303$$

$$= 0.064\ dB/km$$

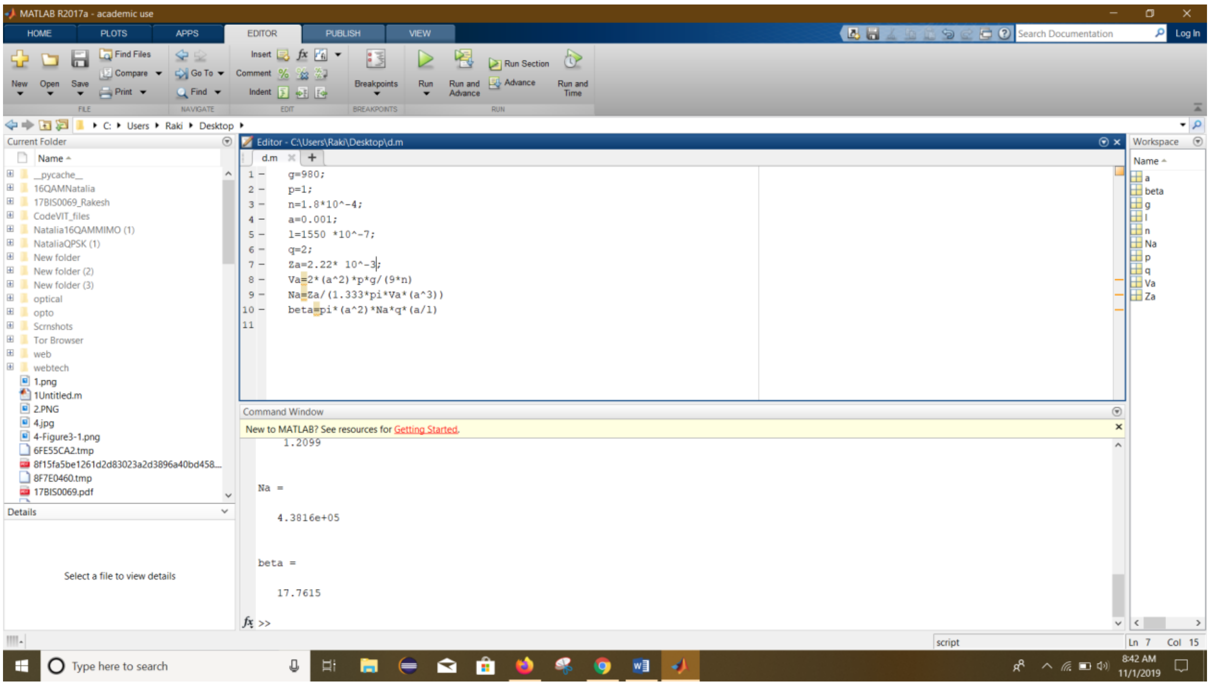
RAIN:



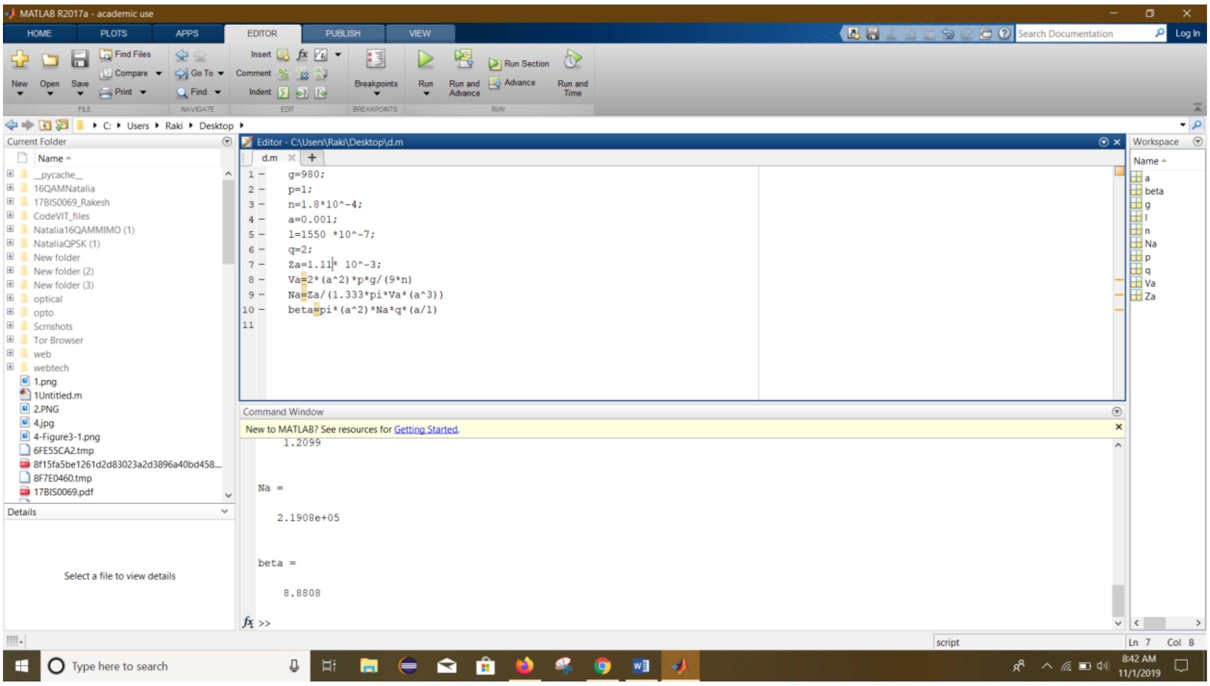
MEDIUM RAIN ATEENUATION:



HEAVY RAIN ATTENUATION:



LIGHT RAIN ATTENUATION:



CONCLUSION :

Nowadays, development in the communications sector is very encouraging. In this article, a numerical expression and simulation modeling of a WDM FSO system have been investigated successfully. External parameters represented the different weather conditions proven the FSO performance was influenced very much by the rain and haze condition. However for the clear weather condition, a 1 km with 2.5 Gbps data rate has been successfully achieved. The simulation results indicate the tradeoff between simulation parameters (data rate, link range and input power). For example, at 2.5 Gbps under clear weather, the BER value of 2.72×10^{-11} is achieved for 1 km, while at 155 Mbps the BER value of 2.19×10^{-8} is achieved for 6 km transmission distance. The effects of weather condition has been presented both theoretically and experimentally (using Optsim) and illustrates some useful comparison. For example, result of a propagation study on an FSO link at 850 nm, 1310 nm and 1550 nm on 1 km long path are presented. Given these wavelength;for longer links, heavy haze, light rain, medium rain and heavy rain become criticalissue. Finally, shortlink range andlow data rate canoptimize the FSO system transmission components.

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