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BER Evaluation of FSO Link for different Duty Cycles of RZ pulse in different conditions of Rainfall

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Abstract:

Free-space optical communication (FSO) systems (in space and inside the atmosphere) have developed in response to a growing need for high-speed and tap-proof communication systems. FSO can carry full-duplex data at Gbps rates over metropolitan distances of a few city blocks to a few kilometers. FSO system requires capital outlay less compared to ground based fiber-optic technologies. FSO systems can be used in metro network extensions. Organizations can deploy FSO to extend existing fiber network to connect to new networks. FSO can also act as back up for fiber optic system.

Keywords — FSO (Free space optics), RZ (Return to zero), NRZ (Non return to zero), NRZ RC (Non return to zero raised cosine), RZ RC (Return to zero raised cosine), OOK (On off keying)

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1. INTRODUCTION

In the past three decades, the demand for high-speed communications has increased dramatically, while fiber optical communications has been applied in the majority of data transmission networks. Optical fiber has advantages over existing copper wire in long distance and high demand applications. The ever increasing need for higher bandwidth and higher speed optical data and communications transmission is driving the development of 100 gigabit per second (Gbps) communication links. However, infrastructure development within cities is relatively difficult and time-consuming, and fiber-optic systems are complex and expensive. Due to these difficulties, free space optical links are the best options. But the link performance of FSO link is dependent on atmospheric effects such as fog, rain and snow. These atmospheric effects cause attenuation to optical signal. Specific rain attenuation γ_{rain}(dB/km) is given by the relation [1]:

$$\gamma_{rain} = k.R^{\alpha} \qquad (1)$$

where R represents rainfall rate (mm/hr) and k, α are power law parameters. These parameters are dependent on [2]:

- Frequency of the signal
- Rain drop size distribution
- Rain temperature

Different rain conditions and their rainfall rate (mm/h) are [3]:

Table: 1.2 Precipitation and rainfall rate

Precipitation	Amount (mm/h)
Light rain	2.5
Medium rain	12.5
Heavy rain	25
Cloud Burst	100

The performance of FSO link is dependent on the modulations scheme adopted [5]. OOK is the simple and widely adopted modulation scheme used in commercial FSO communication system because of ease in implementation, simple receiver design, bandwidth efficiency and cost effectiveness.

RZ modulation format is best for long distance. Where NRZ is used for short distance and it is less complex, cheaper in comparison to RZ [6].
For calculating the attenuation due to rain it is assumed that the raindrop shape is spherical. Due to this assumption k and α becomes independent of polarization [2]. Analysis on the effect of rain on FSO link can be done by knowing the rain attenuation on FSO links and corresponding rainfall intensity. The modeling of rain attenuation prediction can be done using two methods, namely empirical method and the physical method [4].
Choosing k=1.58 and α = 0.63 the attenuation for different rain conditions will be as follows:

- Light Rain = 2.8148 dB/km
- Medium Rain = 7.7573 dB/km
- Heavy Rain = 12.0049 dB/km
- Cloud Burst = 28.7513 dB/km

2. SCHEMATIC DESCRIPTION

The investigation on the effect of duty cycle on BER for different condition of rain fall is done by modeling the in OptiSystem 7.

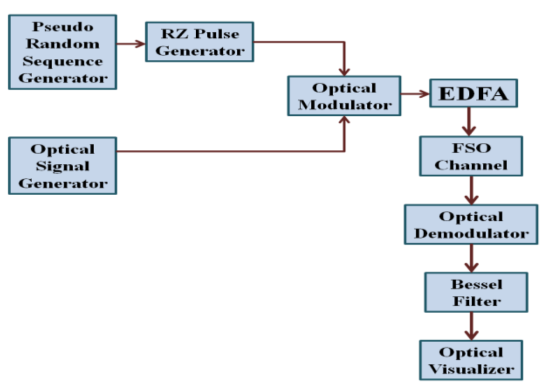

Figure2.1: Schematic Diagram of FSO system

On the transmitter side, pseudo random bit sequence generator generates signal randomly to be transmitted. According to this random sequence RZ pulse generator, generates electrical signal. Optical signal generator (laser source) generates signal in THz frequency range. The signal from pulse generator and laser source are modulated in optical modulator and sent over free space channel. The FSO channel affects the quality of the link, due to atmospheric turbulence. On the receiver side the optical demodulator accepts the optical signal from the FSO channel, converts it into electrical form. The performance of the received signal can be analyzed by visualizer tools as eye diagram analyzer or BER analyzer (Bit error rate analyzer).
N. Chand et al. (2005) purposed the performance of FSO link is dependent on the modulations scheme adopted. OOK is the simple and widely adopted modulation scheme used in commercial FSO communication system because of ease in implementation, simple receiver design, bandwidth efficiency and cost effectiveness.
Jitendra Singh et al. (2013) compared different modulation format RZ, CRZ, CSRZ and NRZ on free space optical communication system. It has been observed that external modulation gave better performance in comparison to direct modulation because direct NRZ spectrum has a strong carrier component compared to external modulated NRZ. Simulation results showed RZ modulation format is best for long distance. Where NRZ is used for short distance and it is less complex, cheaper in comparison to RZ. The performance of these pulse formats have not been investigated in specific weather conditions.

3. RESULTS AND DISCUSSION

To investigate the effect of duty cycle on BER the launched power is kept at different values depending on the attenuation in different cases of rainfall.

3.1Light Rain condition

To investigate the effect of duty cycle on BER the launched power is kept at -12 dBm. The link range is varied from 1 Km to 3 Kms and duty cycle of RZ pulse is varied from 0.1 to 0.7. The attenuation for light rain is 2.8148 dB/Km.

The BER values for different link range with varying duty cycle are presented in table 3.2 and the results are plotted in figure 3.10.

Table 3.1: BER for various duty cycles at different link ranges in light rain

Duty cycle	Link Range				
	1 Km	1.5 Kms	2 Kms	2.5 Kms	3Kms
0.1	$1.3\times10^{-}$	$1.7\times10^{-}$	$1.4\times10^{-}$	$1.8\times10^{-}$	$1.4\times10^{-}$
0.2	$2.2\times10^{-}$	$2.3\times10^{-}$	$1.4\times10^{-}$	$1.4\times10^{-}$	$1.7\times10^{-}$
0.3	$1.9\times10^{-}$	$6.7\times10^{-}$	$3.3\times10^{-}$	2×10^{-1}	4.6×10
0.4	3×10^{-89}	2×10^{-87}	$9.6\times10^{-}$	2.8×10	4.4×10
0.5	$2.6\times10^{-}$	$5.7\times10^{-}$	6.7×10	3.9×10	$1.1\times10^{-}$
0.6	$2.4\times10^{-}$	3×10^{-19}	$1.3\times10^{-}$	4.7×10	2×10^{-14}
0.7	$1.7\times10^{-}$	$1.9\times10^{-}$	$3.3\times10^{-}$	1×10^{-8}	$8.4\times10^{-}$

From the table 3.1, it can be seen that, upto link range of 2.5 Kms duty cycle of 0.2 works best, giving minimum BER. After increasing the link range from 2.5 Kms to 3 Kms duty cycle 0.3 gives best results..

At link range of 3 Kms, BER decreases upto duty cycle 0.3 and then with further increase in duty cycle BER starts to increase. From the results, it can be concluded that optimum duty cycle varies with distance.

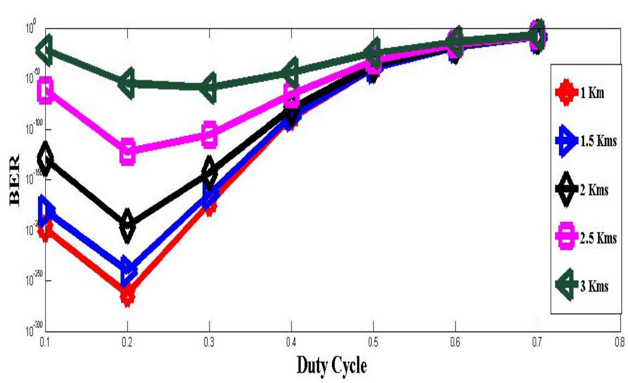

Figure 3.1: BER vs. duty cycle (light rain)

3.2 Medium Rain condition

The BER values for different link range with varying duty cycle are presented in table 3.3 and the results are plotted in figure 3.12.The attenuation for medium rain is 7.7573 dB/km. therefore to achieve the objective of BER less than 10^{-9}, the launched power is increased from -12 dBm to -4 dBm. The link range is varied from 1 Km to 3 Kms. Duty cycle of RZ pulse is varied from 0.1 to 0.6.

Table 3.2: BER for various duty cycles at different link ranges in medium rain

Duty Cycle	Link Range (Kms)				
	1 Kms	1.5 Kms	2 Kms	2.5 Kms	3Kms
0.1	0	7.2×10^{-2}	$6.4\times10^{-}$	$7.8\times10^{-}$	1
0.2	0	8.9×10^{-2}	1.2×10^{-7}	$8.3\times10^{-}$	1
0.3	1.5×10^{-2}	1.5×10^{-1}	1.2×10^{-6}	$5.3\times10^{-}$	1
0.4	5.1×10^{-9}	6.3×10^{-8}	1.1×10^{-4}	$4.4\times10^{-}$	1
0.5	$2.2\times10^{-}$	1.1×10^{-3}	1.8×10^{-2}	$1.8\times10^{-}$	1
0.6	5.1×10^{-2}	$4.2\times10^{-}$	$7.4\times10^{-}$	$4.8\times10^{-}$	1

From the table 3.2, it is clear that upto link range of 2 Kms, with each duty cycle the objective of BER less than 10^{-9} can be achieved. But for link range of 2.5 Kms, transmission is possible with duty cycles, upto 0.3. Further increasing the duty cycle gives BER greater than 10^{-9}.

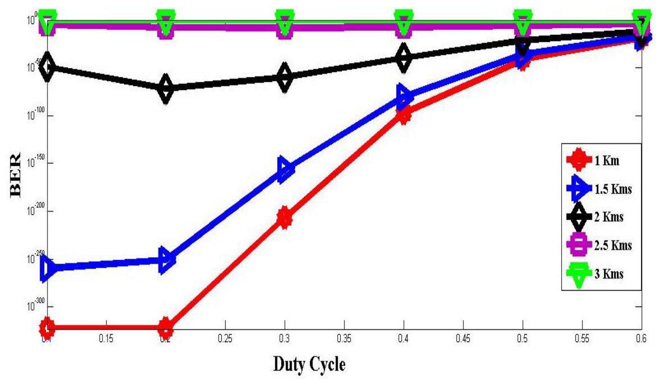

Figure 3.2: BER vs. duty cycle (medium rain)

3.3 Heavy Rain condition

Toachieve the objective of BER less than 10^{-9}, in heavy rain condition with attenuation 12.0049 dB/Km, the launched power is 0 dBm. The link range is varied from 1 Km to 2 Kms. Duty cycle of RZ pulse is varied from 0.1 to 0.5.

The BER values for different link range with varying duty cycle are presented in table 3.3 and the results are plotted in figure 3.14.

Table 3.3: BER for various duty cycles at different link ranges in heavy rain

Duty Cycle	Link Range (Kms)					
	1 Kms	1.2 Kms	1.4 Kms	1.6 Kms	1.8 Kms	2 Kms
0.1	0	1.5e-308	9.1 ×e-146	6.2 ×e-46	1.5 ×e-12	4.2 ×e-4
0.2	0	1.7e-259	2.8 ×e-148	2× e-55	9.3 ×e-16	6.9 ×e-5
0.3	1×10^{-193}	1×e-156	1.3 ×e-101	7× e-45	2.7 ×e-14	1.1 ×e-4
0.4	4.7e-92	3.1× e-79	5.1 ×e-58	4.3 ×e-31	1× e-11	3.1 ×e-4
0.5	4.3e-40	7.8× e-36	1.3 ×e-28	3.3 ×e-18	1.4 ×e-8	1.2 ×e-3

From the table 3.4, it is clear that upto link range of 1.6 Kms, with each duty cycle the objective of BER less than 10^{-9} can be achieved. Increasing the link range to 1.8 Kms, transmission is possible, upto duty cycle 0.4. Further increasing the duty cycle gives BER greater than 10^{-9}. Also increasing the link range increases BER.

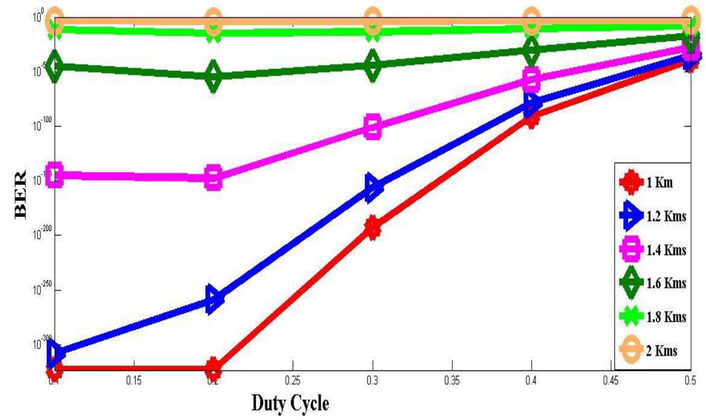

Figure 3.3: BER vs. duty cycle (heavy rain)

3.4 For Cloud burst

Toachieve the objective of BER less than 10^{-9}, the launched power is 10 dBm. The link range is varied from 200 m to 1000 m. Duty cycle of RZ pulse is varied from 0.1 to 0.5.

The BER values for different link range with varying duty cycle are presented in table 3.5 and the results are plotted in figure 3.16.

Table 3.4: BER for various duty cycles at different link ranges in cloud burst

Duty Cycle	Link Range (meters)				
	200 m	400 m	600 m	800 m	1000 m
0.1	0	0	0	3×e-141	2.5×e-9
0.2	0	0	0	1.1× e-127	1.5×e-9
0.3	8.1× e-55	2.1× e-237	6.1× e-193	3.8× e-87	2.3×e-8
0.4	5.1× e-109	4.5× e-104	2×e-90	4.7× e-51	4.9×e-7
0.5	2.6× e-45	9.5× e-44	2.3× e-39	6.3× e-26	1.4×e-5

From the table 3.4, it can be seen that upto link range of 600 meters the BER values are 0 for duty cycle of 0.1 and 0.2 but at link range of 800 meters the lowest BER is achieved at 0.1 duty cycle. Increasing the link range to 1 Km again lowest BER is obtained at duty cycle of 0.1. For the same link range increasing the duty cycle after 0.2 the BER achieved is higher than 10^{-9}.

From the table, it is observed that 0.1 duty cycle best results for all the link ranges.

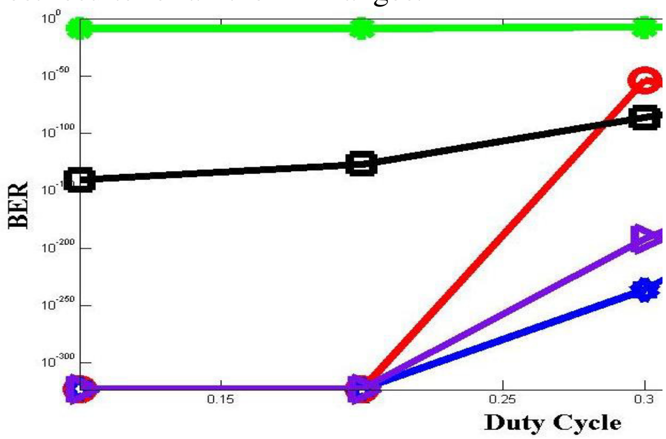

Figure3.4: BER vs. duty cycle (cloud burst)

4. CONCLUSIONS

By comparing all the results for different duty cycles in different conditions of rainfall with different attenuations the following tables are obtained

Table 4.1: Optimum duty cycle (Light and Medium rain)

Link Range	Optimum duty cycle in light rain	Optimum duty cycle in medium rain
1 Km	0.2	0.2
1.5 Kms	0.2	0.2
2 Kms	0.2	0.2
2.5 Kms	0.3	0.2
3 Kms	0.3	Transmission not possible upto 10 dBm of launched power

Table 4.2: Optimum duty cycle (Heavy rain)

Link Range	Optimum duty cycle in heavy rain
1 Km	0.1
1.2 Kms	0.1
1.4 Kms	0.2
1.6 Kms	0.2
1.8 Kms	0.2
2 Kms	Transmission not possible upto 10 dBm of launched power

Table 4.3: Optimum duty cycle (Cloud burst)

Link Range	Optimum duty cycle in cloud burst
200 m	0.1
400 m	0.1
600 m	0.1
800 m	0.1
1000 m	0.1

By comparing the results in different rain conditions following conclusions are obtained:

- For light rain condition upto 2.5 Kms, 0.2 duty cycle gives lowest BER. Increasing the link range from 2.5 Kms to 3 Kms, lowest BER is obtained at 0.3 duty cycle.
- In medium rain, upto link range of 2.5 Kms, duty cycle of 0.2 gives lowest BER. In medium rain condition, link range of 3 Kms is not possible even on launched power of 10 dBm.
- In heavy rain for investigation, link range is reduced. The link range is varied from 1 Km to 2 Kms due to high attenuation. Upto 1.2 Kms duty cycle 0.1 gives best results. Increasing the link range from 1.2 Kms to 1.8 Kms, best results are found at duty cycle of 0.2.
- In case of cloud burst, 0.1 duty cycle gives lowest BER for all the link ranges i.e from 200 m to 1000 m.

  BER vs. Duty cycle in different rain conditions is plotted in the figure 3.18

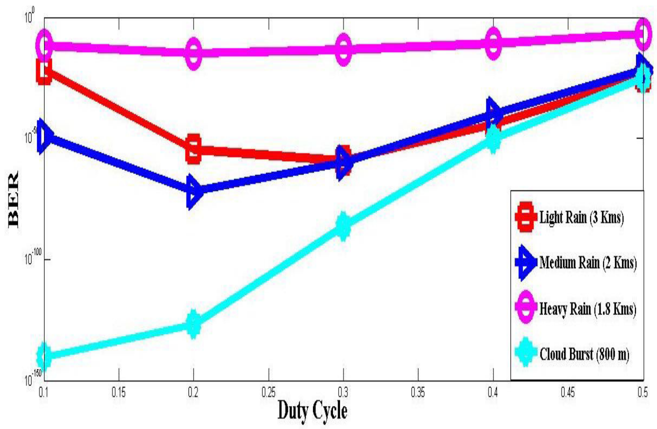

Figure 4.1: BER vs. duty cycle (comparison of all rain conditions)

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