

Seasonal Signal Attenuation in Free-Space Optical Links: A Case Study of Coastal Regions (Goa, Odisha, Kanyakumari)

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Abstract: Free-Space Optics (FSO) presents a compelling alternative for high-bandwidth communication, offering rapid deployment and cost-effectiveness compared to traditional wired systems.

1 However, FSO systems are susceptible to atmospheric conditions, particularly in coastal regions characterized by significant seasonal variations in weather. 2 This study investigates the impact of seasonal signal attenuation on FSO links operating in three distinct coastal regions of India: Goa, Odisha, and Kanyakumari. Utilizing Differential Phase-Shift Keying (DPSK) modulation, the research evaluates the performance of FSO systems by analyzing key metrics such as bit error rate (BER) and link availability across different seasons, considering factors like rainfall, fog, and atmospheric turbulence. The findings of this study aim to provide valuable insights into the feasibility and reliability of FSO deployments in challenging coastal environments, contributing to the development of robust and resilient FSO communication systems for diverse applications.

Keywords: Bit error rate; Link distance; Attenuation; multiplexing; free space optic.

1. Introduction

Free-Space Optics (FSO) has emerged as a promising technology for high-speed wireless communication, offering several advantages over traditional radio frequency (RF) systems. These include rapid deployment, cost-effectiveness, and the ability to achieve significantly higher data rates, reaching up to 2.5 Gbps. FSO leverages light as the carrier wave, transmitting data through the atmosphere over distances ranging from a few hundred meters to several kilometers. While FSO presents a compelling alternative for various applications, its performance is susceptible to atmospheric conditions, particularly in regions with significant seasonal variations. This study focuses on the impact of seasonal signal attenuation on FSO links operating in three distinct coastal regions of India: Goa, Odisha, and Kanyakumari. Utilizing Differential Phase-Shift Keying (DPSK) modulation, a robust technique for optical communication, this research aims to investigate the influence of factors such as rainfall, fog, and atmospheric turbulence on FSO link performance, specifically analyzing key metrics like bit error rate (BER) and link availability across different seasons. The findings of this study will provide valuable insights into the feasibility and reliability of FSO deployments in challenging coastal environments, contributing to the development of more robust and resilient FSO communication systems.

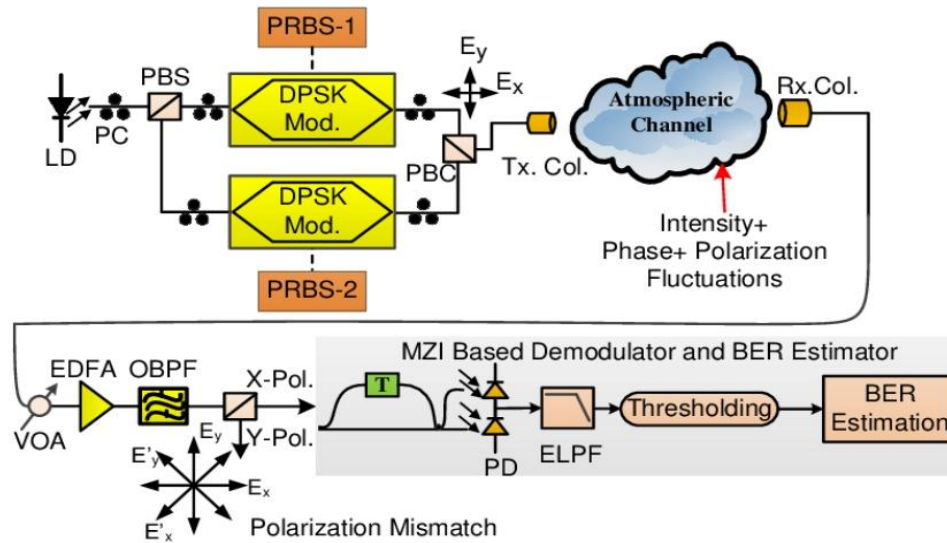


Fig.1 Model of DPSK

Description of FSO System using DPSK

In Free-Space Optics (FSO), communication relies on transmitting optical signals through the atmosphere. A typical FSO system comprises a transmitter, a channel, and a receiver. The transmitter utilizes a continuous-wave laser and employs Differential Phase-Shift Keying (DPSK) modulation to encode data onto the optical carrier. This modulated signal then traverses the free-space channel, which in coastal regions is significantly influenced by seasonal variations in weather conditions, such as rainfall, fog, and atmospheric turbulence. At the receiver, the attenuated signal is amplified by an Erbium-Doped Fiber Amplifier (EDFA), converted into an electrical signal by a photodetector, and then processed to demodulate the original data stream. The performance of the received signal is evaluated by analyzing key metrics like Bit Error Rate (BER) and link availability.

Design of system layout:

The figure represents a simulation setup for a Free-Space Optical (FSO) communication system employing Differential Phase-Shift Keying (DPSK) modulation. The system begins with a Pseudo-Random Bit Sequence Generator (PRBS), which creates the binary input data stream that drives the DPSK modulation. A continuous-wave (CW) laser, operating at a wavelength of 1555 nm and a power of 10 mW, provides the optical carrier signal, which is modulated using a Mach-Zehnder Modulator (MZ Modulator) to encode the input data. The modulated signal is amplified by an optical amplifier with a gain of 20 dB and a noise figure of 4 dB before being transmitted through the FSO channel. The channel introduces attenuation and noise to simulate real-world environmental effects, such as weather-induced signal degradation, with attenuation modeled at 0.2984 dB/km over a range of 0.5 km.

At the receiver, the optical signal is detected by an Avalanche Photodiode (APD), which converts it into an electrical signal. The received signal is then passed through a low-pass Bessel filter to eliminate high-frequency noise, preserving the baseband signal. A 3R regenerator (Re-amplify, Re-shape, Re-time) is used to restore the signal by compensating for distortions caused by attenuation and noise. The system performance is evaluated using a Bit Error Rate (BER) analyzer, which measures the communication quality, and an eye diagram analyzer, which visualizes signal integrity. Additionally, oscilloscope visualizers display the transmitted and received waveforms in the time domain, while optical and electrical power meters monitor power levels throughout the system. This setup is designed to analyze the impact of attenuation and noise on the FSO communication system, providing insights into signal quality, Q-factor, and system reliability under varying conditions.

Table 1: Quality of Signal Across Different Locations Based on Range (KM)

Range(KM)	Quality_of_Carb_Goa	Quality_of_Carb_Odisha	Quality_of_Carb_Kanyakumari
1	810.203	789.34	819.515
2	388.129	407.257	522.043
3	219.502	212.53	352.328
4	136.546	131.758	225.485
5	84.343	78.383	173.393
6	57.0036	48.8902	134.35

7	37.4687	32.9574	102.103
8	24.6943	22.0878	82.6891
9	16.8518	14.3243	62.9014
10	11.4117	9.35784	53.5146
11	7.66148	6.23374	44.4169
12	4.87977	3.85409	36.1318
13	3.03129	0	30.829
14	0	0	24.969
15	0	0	22.4375
16	0	0	17.7973
17	0	0	15.6587
18	0	0	13.3839
19	0	0	10.6474
20	0	0	9.46434
21	0	0	8.01562
22	0	0	6.57421
23	0	0	5.43556
24	0	0	4.69975
25	0	0	3.95138
26	0	0	3.16985
27	0	0	0

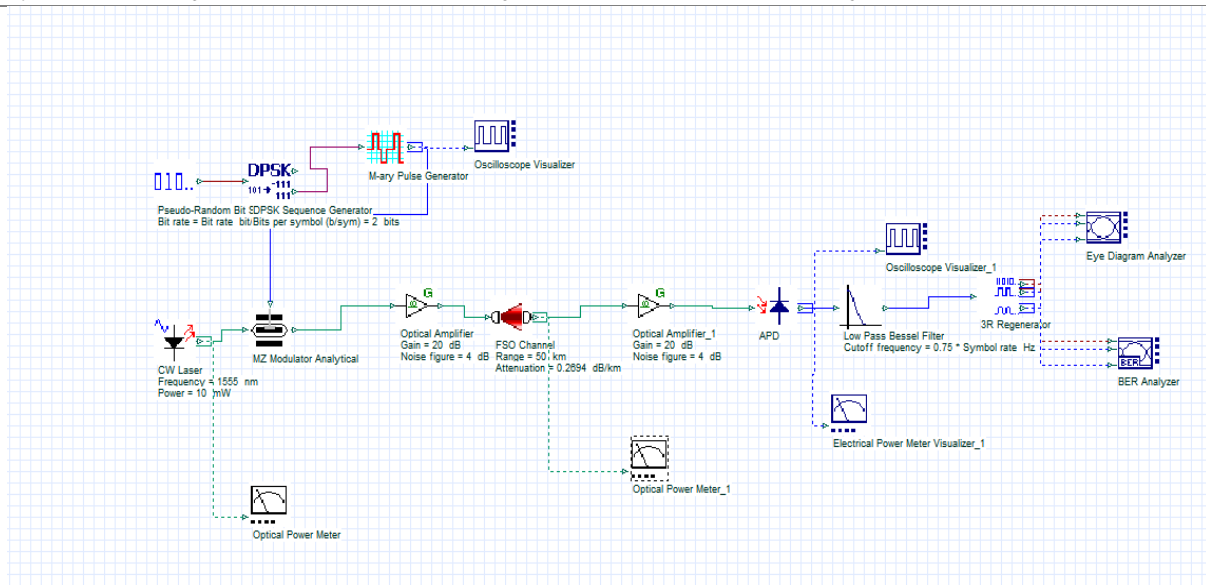


Fig 2: System layout 1 for 1550 nm laser

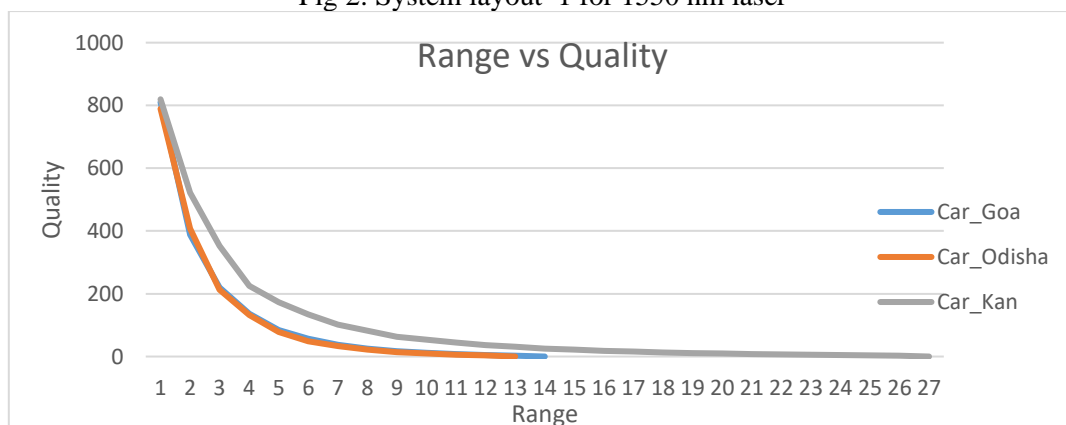


Fig.3.The line graph Carbonneau Model between three Region

Table 2: Quality of Signal Across Different Locations Based on Range (KM)(Japan)

Range(KM)	Quality_of_Goa	Quality_of_Odisha	Quality_of_KanyaKumari
1	746.264	744.87	849.005
2	344.748	330.067	467.043
3	171.397	156.765	298.461
4	86.6325	84.4062	196.292
5	51.5083	48.606	138.874

6	30.8131	25.9208	97.9411
7	17.6358	15.3932	71.5298
8	10.1786	8.62354	57.0679
9	5.907	4.55123	42.5906
10	3.25514	0	36.0998
11	0	0	26.4339

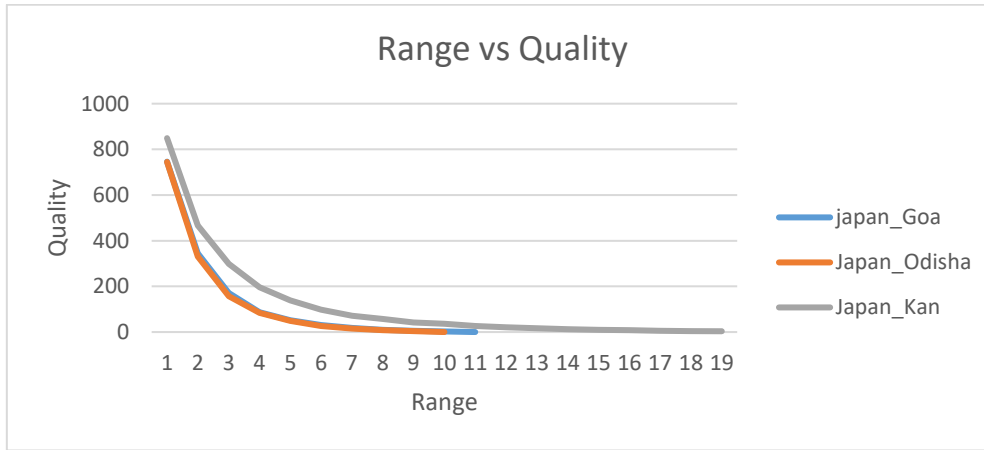


Fig.3.The line graph Japan Model between three Region

Table 3: Quality of Signal Across Different Locations Based on Range (KM)(Samir)

Range (KM)	Quality_of_Goa	Quality_of_Odisha	Quality_of_KanyaKumari
1	649.092	798.872	475.796
3	112.361	103.886	271.46
4	52.2529	44.9895	168.992
5	23.6669	20.4661	120.393
6	12.1628	9.65769	86.9965
7	5.58656	3.89908	62.8649
8	0	0	44.0548
9	0	0	34.1759

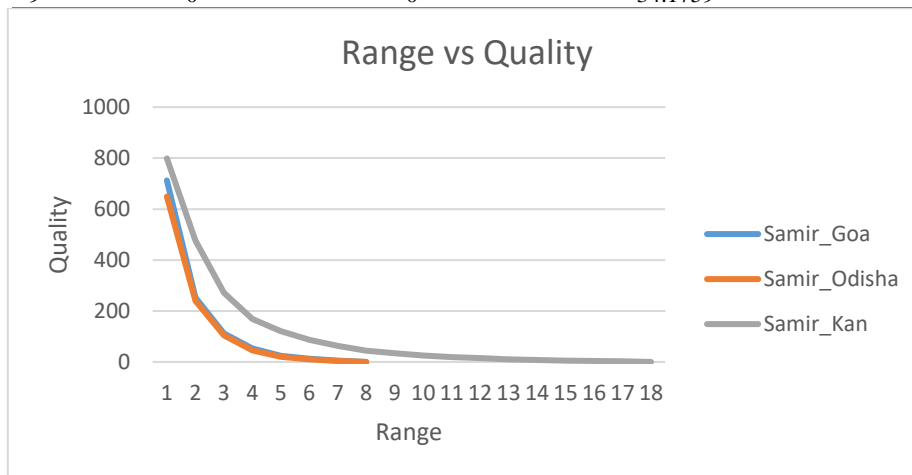


Fig.3.The line graph Samir Model between three Region

Table 3: Quality of Signal Across Different Locations Based on Range (KM)(Suriza)

Range(KM)	Quality_of_Goa	Quality_of_Odisha	Quality_of_KanyaKumari
1	818.098	856.108	902.684
2	487.373	467.136	567.378
3	312.161	305.23	374.685
4	205.299	211.303	280.053
5	156.201	152.25	228.183
6	115.311	112.472	178.744
7	90.8197	87.8004	157.196
8	73.6071	68.3341	128.595
9	58.3691	51.3129	109.097
10	46.8614	41.6263	100.188
11	36.4868	32.9504	82.6806
12	30.1258	27.3126	76.3977

13	24.3632	21.1157	67.0592
14	19.3876	17.4883	61.0241
15	16.3748	14.4277	54.987

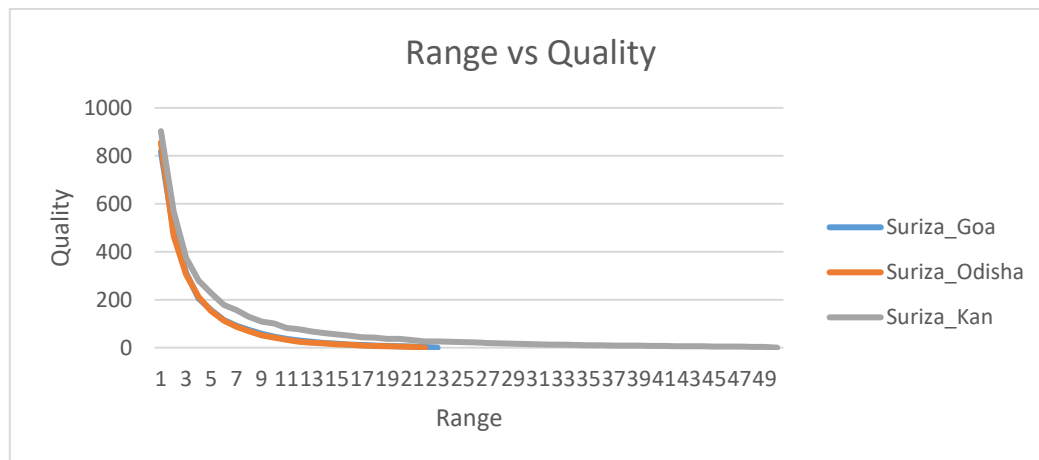


Fig4.The line graph Suriza Model between three Region

Table.5 Rain attenuation models

S. No	Model	k	α
1	Carbonneau	1.076	0.67
2	Japan	1.58	0.63
3	Samir	2.03	0.74
4	Suriza	0.4195	0.8486

The table lists parameters for different optical models—Carbonneau, Japan, Samir, and Suriza—used to describe signal attenuation in optical communication systems. Each model is defined by coefficients (k) and (alpha). The Carbonneau model has a moderate k value of 1.076 and an alpha of 0.67, indicating a balanced attenuation. The Japan model features a higher (k) of 1.58 and a slightly lower (alpha) of 0.63, suggesting stronger attenuation characteristics. The Samir model shows the highest (k) value at 2.03 and an (alpha) of 0.74, indicating significant and rapid signal loss over distance. Conversely, the Suriza model has the lowest(k) at 0.4195, implying minimal initial attenuation, but with a high (alpha) of 0.8486, it suggests a steep rate of signal degradation. These models help engineers predict signal behavior in various environments, aiding in the design of efficient optical communication systems.

Table 3: Various attenuations values for different cities(Suriza)

Weather Condition	Input Power (W)	Attenuation (dB/km)	Range (km)	Q-factor	BER	Output Power Fso(nW)
Goa Rainfall						
Rain	10	0.9064	1	818.098	0	6.119
	10	0.9064	15	16.3748	1.13E-60	-29.94
	10	0.9064	23	0	1	-40.74
Odisha Rainfall						
Rain	10	0.9790	1	856.108	0	5.966
	10	0.9790	11	32.9504	1.44E-238	-24.472
	10	0.9790	22	0	1	-41.188
Kanyakumari Rainfall						
Rain	10	0.2694	1	902.684	0	6.56
	10	0.2694	25	23.2821	2.56E-120	-27.382
	10	0.2694	50	0	1	-40.327

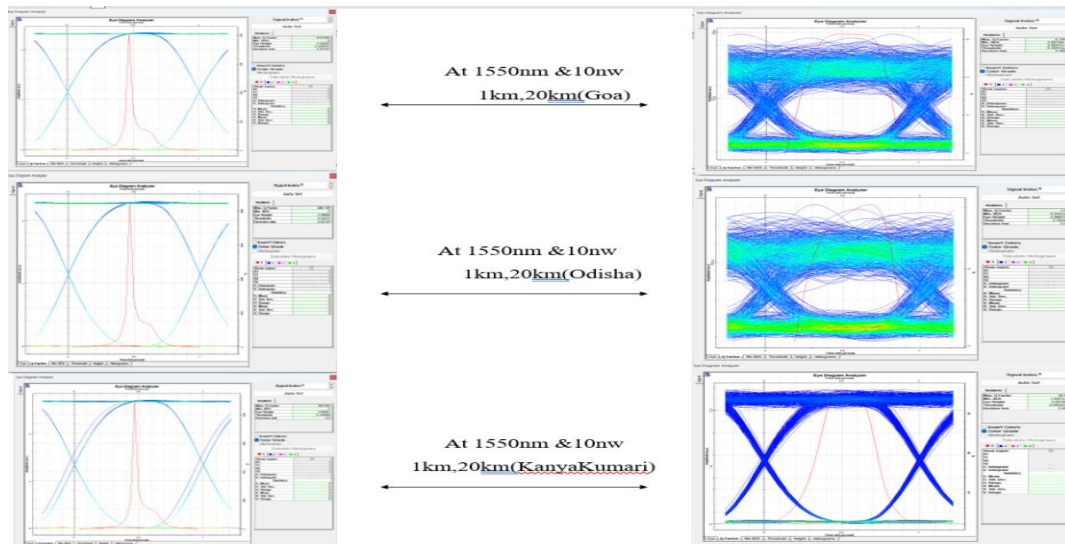


Fig-6 Suriza Model of three cities Values and graph

Table 3: Various attenuations values for different cities(Carbonneau)

Weather Condition	Input Power (W)	Attenuation (dB/km)	Range (km)	Q-factor	BER	Output Power Fso(nW)
Goa Rainfall						
Rain	10	1.9770	1	810.203	0	4.903
	10	1.9770	8	24.6943	4.25E-135	-27.065
	10	1.9770	14	0	1	-43.49
Odisha Rainfall						
Rain	10	2.1009	1	789.34	0	4.909
	10	2.1009	7	32.9574	1.07E-238	-24.36
	10	2.1009	13	0	1	-42.089
Kanyakumari Rainfall						
Rain	10	0.7585	1	819.515	0	5.901
	10	0.7585	14	24.969	4.80E-138	-26.398
	10	0.7585	27	0	1	-41.923

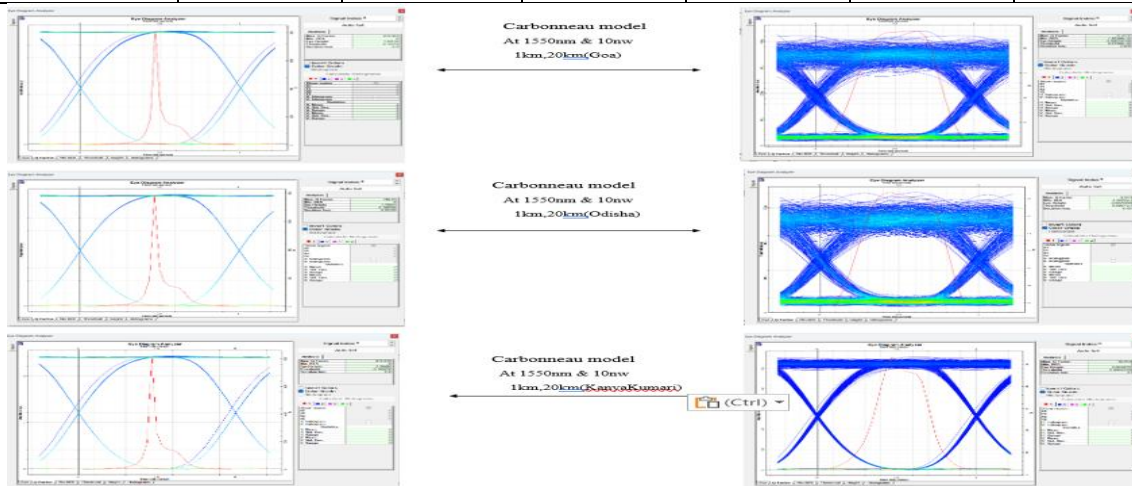


Fig-7 Carbonneau Model of three cities Values and Graph

Table 3: Various attenuations values for different cities(Japan)

Weather Condition	Input Power (W)	Attenuation (dB/km)	Range (km)	Q-factor	BER	Output Power Fso(nW)
Goa Rainfall						
Rain	10	2.7995	1	746.264	0	3.736
	10	2.7995	6	30.8131	5.73E-209	-25.646
	10	2.7995	11	0	1	-44.499
Odisha Rainfall						
Rain	10	2.9641	1	744.87	0	4.325
	10	2.9641	6	25.9208	1.47E-148	-25.88
	10	2.9641	10	0	1	-42.805
Kanyakumari Rainfall						

Rain	10	1.1373	1	849.005	0	5.522
	10	1.1373	10	36.0998	8.05E-286	-24.203
	10	1.1373	20	0	1	-41.427

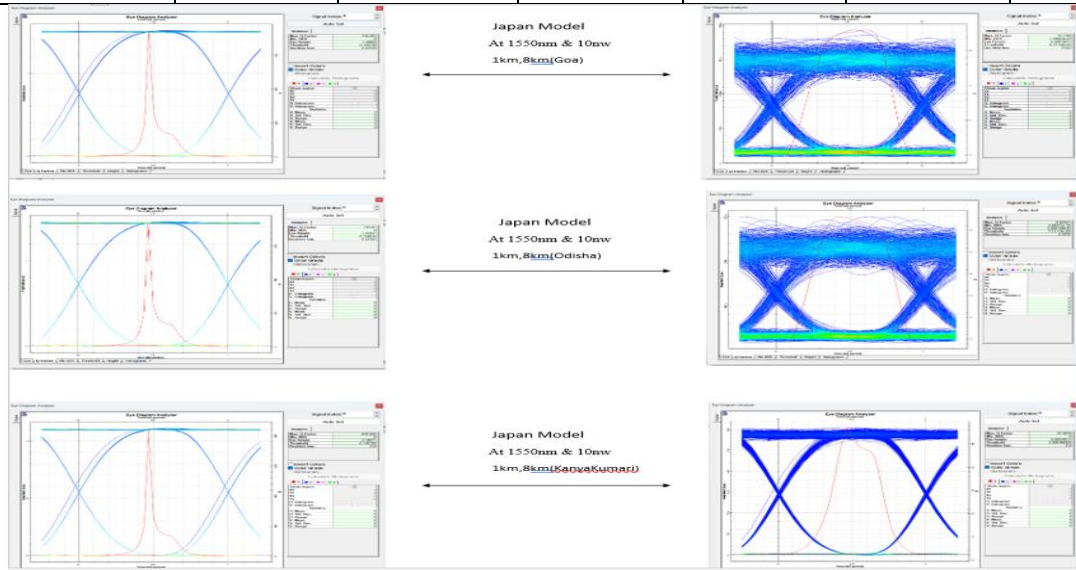


Fig-8 Japan Model of three cities Values and Graph

Table 4: Various attenuations values for different cities(Samir)

Weather Condition	Input Power (W)	Attenuation (dB/km)	Range (km)	Q-factor	BER	Output Power Fso(nW)
Goa Rainfall						
Rain	10	3.9746	1	712.271	0	2.937
	10	3.9746	5	23.6669	3.09E-124	-26.592
	10	3.9746	8	0	1	-43.065
Odisha Rainfall						
Rain	10	4.2505	1	649.092	0	2.963
	10	4.2505	5	20.4661	1.69E-93	-27.772
	10	4.2505	8	0	1	-44.711
Kanyakumari Rainfall						
Rain	10	1.3798	1	798.872	0	5.598
	10	1.3798	9	34.1759	1.80E-256	-24.671
	10	1.3798	18	0	1	-42.746

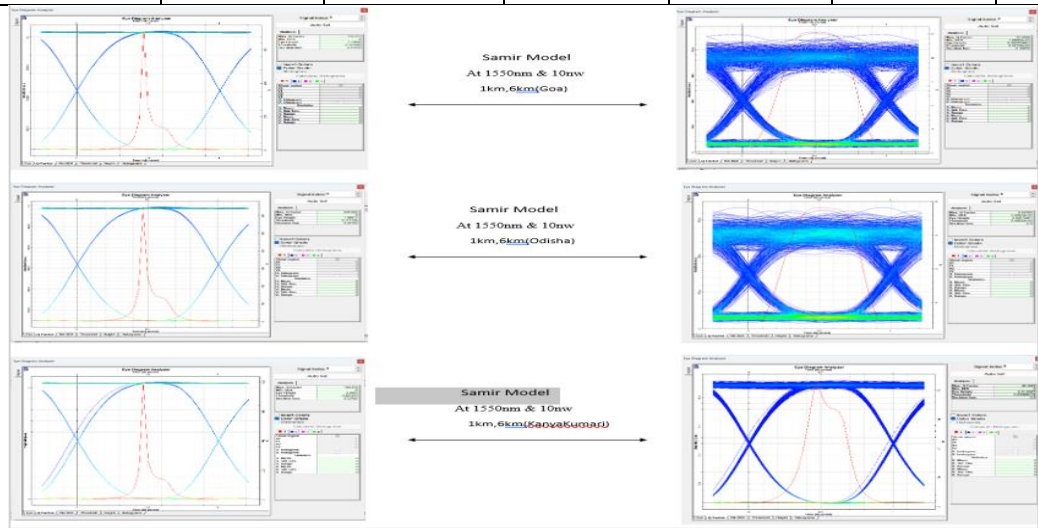


Fig-9 Samir Model of three cities Values and Graph

2. Conclusion

This study on Seasonal Signal Attenuation in Free-Space Optical Links highlights the challenges and advancements in communication technologies across coastal regions, specifically Goa, Odisha, and Kanyakumari, using DPSK (Differential Phase-Shift Keying). The analysis of signal attenuation under

diverse weather conditions provides critical insights into the performance of Free-Space Optical (FSO) communication systems.

The results emphasize that environmental factors such as rainfall significantly impact the attenuation and Q-factor of the optical signal. Among the tested systems, System 2 consistently demonstrated superior performance, achieving higher Q values and better resilience against signal losses, even under adverse weather conditions like heavy rainfall. By optimizing parameters, System 2's use of a single laser not only minimizes losses but also simplifies circuitry, proving to be more efficient and cost-effective for FSO applications in such regions.

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