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Work on the Evaluation Parameters of Serial and Parallel Relay-Assisted FSO System

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Abstract: The outage performance of FSO system assisted with decode and forward relay is studied using diversity techniques like wavelength and time which helps in mitigating atmospheric turbulence. The channel modelled using Malaga turbulence model with the combined effects of path loss and pointing errors. We derive outage performance analysis for multi hop system using no, wavelength and time diversity schemes, respectively. And we justified the usage of diversity techniques, Because of which the FSO system performance gets enhanced.

Keywords: pointing error, M-distribution, path loss, wavelength diversity, multi-hop parallel FSO system

1 Introduction

FSO is driving force in Wireless communication system. Since it has established as an innovative technology which bolsters channel capacity and high bit rate and furthermore highly secure at low deployment cost and also no spectrum allocation required as in radio frequency [1–4]. Yet comes with some grave disadvantages like Atmospheric turbulence, multi path loss and pointing errors. The consistent shaking of the surface of the earth results in pointing error. Absence of clean particles in atmosphere and presence of haze, mist and unevenly distributed temperature is responsible for turbulence and scintillation. These above-mentioned effects are responsible for signal deterioration and play a decisive role in signal malformation and also FSO transmission system turns inefficient and unreliable [8].

As FSO systems turns inefficient and unreliable for long distance transmissions more than 1 km. The attenuation will be more for very long distance which is inappropriate for efficient FSO system. Relays in FSO acts as panacea for the above-mentioned problem and ameliorate attenuation to some level. Idea is effectively using repeaters periodically, which is called as relaying transmission in FSO system, by doing so link length gets increases and also attenuation drops which gained prominence in recent times. Numerous works proposed in the literature for both serial and parallel relaying. In [5–7], the execution of FSO framework has been inspected. These work demonstrate that multi hops transmission is an effective technique to improve the scope region. Since it joins them serially and expands the scope region. Parallel relaying is another, which supports broadcasting with many transmitting antennas. From literature, we conclude that performance of serial is significantly higher than parallel.

From literature we have relays, error control coding, aperture averaging and diversity techniques which helps in accuring the performance of FSO system by minimizing BER. These techniques are implemented in [9, 10]. But in our work, we think about diversity methods to diminish the error bit in information signal. It can be spatial, time and wavelength. In spatial diversity scheme, same data,wavelength has been transmitted over many transceivers to improve BER. In time, same data transmitted over different time slots but signal of same wavelength and frequency with only one pair of transceivers for improving BER of the link. In wavelength diversity, signal sent with many wavelengths.

Several atmospheric turbulence mathematical models for the random fading irradiance signals have been developed like gamma-gamma (GG), negative exponential, log-normal (LN). BER of the multihop DF FSO interface over GG turbulence channels considering the path loss and pointing errors have been considered efficiently in [11]. In any case, LN, GG, K and negative exponential models can be derived from a more aggregated model named M or Malaga distribution, which is proposed in [12]. We consider Malaga (M) turbulence since its closed form probability density function (PDF) covers all turbulence regimes varying from weak to super strong turbulence and all the available models can be derived as shown in Table [1].

In [13], Outage Performance of DF Relay-Assisted FSO Communications Using Time Diversity with gamma gamma channel has been proposed. In [14] Optimal Relay

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Table 1: Channel models derived using M-turbulence model [16].

Distribution model	Conditions
Gamma	$\rho = 0, \gamma = 0$
Gamma-gamma	$\rho = 1, \gamma = 0, \Omega^{'} = 1$
Lognormal	$\rho = 0, \gamma = 0, var[\|U_L\|] = 0$
K distribution	$\rho = 0, \Omega = 0$ or $\beta = 1$
Exponential distribution	$\rho = 0, \Omega = 0$

Placement and Diversity Analysis of Relay-Assisted FSO system for log-normal model has been proposed. In [15] the performances of relay-aided FSO system over M distribution with pointing errors in the presence of various weather conditions have been proposed. In [16] the Performance evaluation of FSO system using wavelength and time diversity over malaga turbulence channel with pointing errors has been derived. In our paper, the outage performance of FSO system assisted with decode and forward (DF) relay is studied extensively using diversity techniques like wavelength and time on M distribution.

The work flow is assigned as following. division 2 deals with system and channel model. In division 3 closed form equation for outage probability is derived. division 4 illustrates the numerical results with plots. Lastly, conclusion in division 5.

2 System and channel model

2.1 FSO system model

An Optical wireless communication system with relays is illustrated in Figure 1. We assume source node(S) at a distance of some X kilometres from destination node(D). Assuming that the source node communicates with a destination node via N + 1 paths, including N parallel paths and a direct link. Let M denote the total hops in each parallel path, that is, there are $M-1$ relays in each path. Relays assume a significant part in accruing the scope limit of the system by enhancing coverage area of the system. Serial Relays are further divided as DF and AF mentioned earlier. We use DF relays in the present work.

The received signal in multi-hop configuration can be assumed as [15]

$$y_{ij} = I_{ij}RP_{ij}X(t) + n(t), \forall i \in (1, ..., N), j \in (1, ..., M) \quad (1)$$

2.2 FSO channel model

In the present paper, the optical channel model I_{ij} is considered as product of I_a, I_p and I_l which is given below [17]

$$I_{ij} = I_l I_a I_p \quad (2)$$

Here I_l is atmospheric loss, I_a is atmospheric turbulence, I_p is pointing errors where I_l is modelled by the Beer Lamberts law as [16]

$$I_l = \exp(-\sigma L) \quad (3)$$

where σ is the attenuation coefficient [15], L is the link length to be 2 km.

In this work, channel used is Malaga turbulence model. The closed form PDF derived is applicable for both plane and spherical wave laser signals considered from weak to super-strong turbulence regimes. Absence of an unifying statistical model which covers all turbulence regimes was missing, Which was fulfilled with invention of M- distribution model also we can derive most of the existing turbulence models shown in Table [1] [18, 19]. The model assumes signal transmission in wireless communication because of atmospheric turbulence there will be signal scattering of three components: (A) (B) and (C) shown in Figure 2. Since no other models in the literature covers all three scattering components. Hence its more valid and novel to derive using M- distribution channel model.

The closed form PDF of the Malaga-distribution turbulence from [15]

$$f_{I_ij}(I_ij) = A\sum_{k=1}^{b} a_k I_ij^{\frac{\alpha+k}{2}-1} K_{\alpha-k}\left(2\sqrt{\frac{\alpha\beta I_ij}{\gamma\beta+\Omega}}\right) \quad (4)$$

$$\text{where } A = \frac{2\alpha^{\frac{\alpha}{2}}}{\gamma^{1+\frac{\alpha}{2}}\Gamma(\alpha)}\left(\frac{\gamma\beta}{\gamma\beta+\Omega'}\right)^{\beta+\frac{\alpha}{2}} \quad (5)$$

$$a_k = \begin{pmatrix}\beta-1\\k-1\end{pmatrix}\frac{(\gamma\beta+\Omega')^{1-\frac{k}{2}}}{k-1!}\left(\frac{\Omega'}{\gamma}\right)^{k-1}\left(\frac{\alpha}{\beta}\right)^{\frac{k}{2}} \quad (6)$$

2.3 Combined channel fading models

The combined channel model including atmospheric loss, atmospheric turbulence and pointing errors for I_{ij} is given as [15]

$$f_{I_ij}(I_ij) = \frac{g^2 A I_{ij}^{-1}}{2}\sum_{K=1}^{\beta}\left(a_k\left[\frac{1}{B}\right]^{\frac{\alpha+K}{2}} G_{1,3}^{3,0}\left(\frac{I_{ij}}{BA_0 I_l}\middle| \begin{matrix}1+g^2\\ g^2, \alpha, k\end{matrix}\right)\right) \quad (7)$$

where $B = \left(\frac{\Omega^1+\gamma m\beta}{\alpha m\beta m}\right)$, $G_{p,q}^{m,n}$ [•] is the Meijer's G-function.

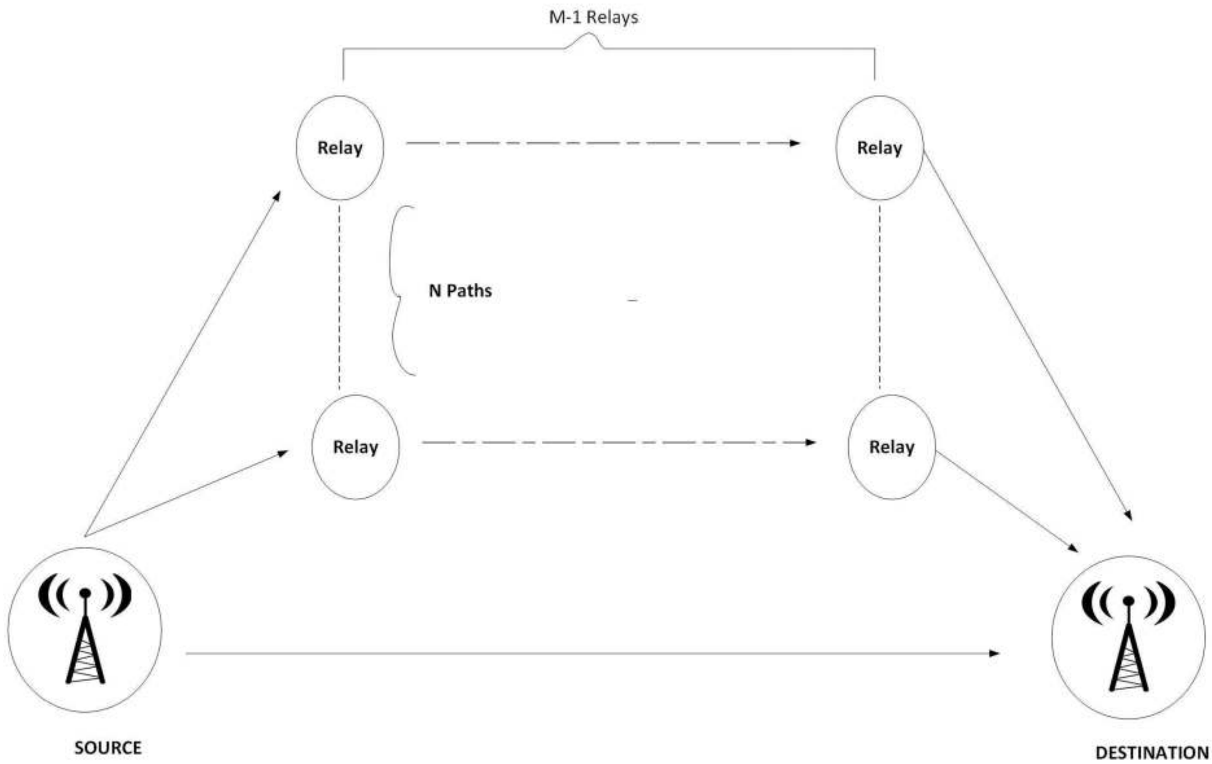

Figure 1: Schematic of Multi-hop DF FSO system.

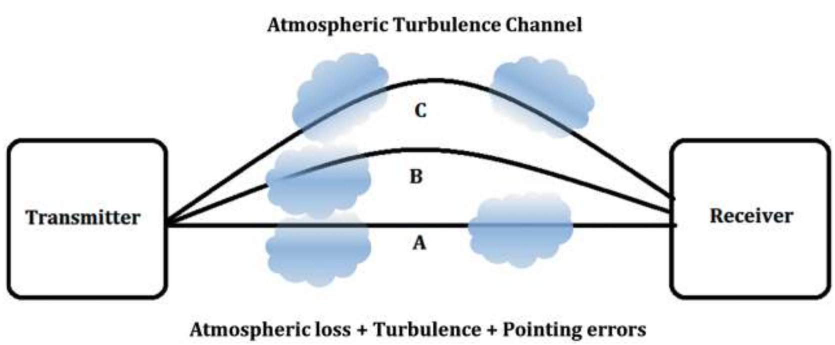

Figure 2: Optical signal transmission in wireless communication system [16].

Thus, the CDF in terms of SNR_{ij}, can be given as [14]

$$F(SNR_{ij}) = \frac{g^2 A}{2} \sum_{K=1}^{\beta} \left(a_k \left[\frac{1}{B} \right]^{\frac{\alpha+K}{2}} G_{2,4}^{3,1} \left(\frac{1}{BA_0 I_l} \sqrt{\frac{SNR_{ij}}{\overline{SNR}_{ij}}} \middle| \begin{matrix} 1, 1+g^2 \\ g^2, \alpha, k, 0 \end{matrix} \right) \right) \tag{8}$$

3 Outage probability

Outage probability is a probability that the received SNR is less than or equal to threshold SNR, SNR_{th}, representing the receiver's sensitivity limit, Means to say that if signal is not equal to the ideal signal prescribed then literally there would be no data transfer in wireless communication system. Hence, Outage probability assumes significance in predicting the performance of system. The outage probability over fading channel is expressed as

$$p_{out_{ij}} = p(SNR(I_{ij}) \leq SNR_{th}) \tag{9}$$

where SNR_{th} is the threshold SNR below which the signal strength of the receiver is less than the acceptable level that is, noise strength will be more than the signal strength.

Following from eq. (8) cumulative distribution function (CDF) for the M distribution is utilized to get the final equation for the estimation of the outage of the FSO as follows

$$p_{out,ij} = \frac{g^2 A}{2} \sum_{K=1}^{\beta} \left(a_k \left[\frac{1}{B} \right]^{\frac{\alpha+K}{2}} G_{2,4}^{3,1} \left(\frac{1}{BA_0 I_l} \sqrt{\frac{SNR_{th}}{\overline{SNR}_{ij}}} \middle| \begin{matrix} 1, 1+g^2 \\ g^2, \alpha, k, 0 \end{matrix} \right) \right) \tag{10}$$

The outage probability of multi-hop coherent FSO system on each relay node uses DF mode, So outage probability of multi-hop system with i path and j hops will be given below [20]

$$p_{out} = 1 - \prod_{i=1}^{L} \prod_{j=1}^{O} (1 - p_{out,ij}) \tag{11}$$

By substituting eq. (10) into eq. (11) we have

$$p_{out} = 1 - \prod_{i=1}^{L} \prod_{j=1}^{O} \left(1 - \frac{g^2 A}{2} \sum_{K=1}^{\beta} \left(a_k \left[\frac{1}{B} \right]^{\frac{\alpha+K}{2}} G_{2,4}^{3,1} \left(\frac{1}{BA_0 I_l} \sqrt{\frac{SNR_{th}}{\overline{SNR}_{ij}}} \middle| \begin{matrix} 1, 1+g^2 \\ g^2, \alpha, k, 0 \end{matrix} \right) \right) \right) \tag{12}$$

3.1 No diversity

The outage probability for this case will be same as mentioned in eq. (14), Since only single signal transmitted.

3.2 Wavelength diversity

Atmospheric turbulence could be considered as one of the major hindrance that FSO communication systems is facing, which degrades the performance in terms of both BER and outage. As the refractive index variation will be different for different wavelengths, the fading is not the same for different wavelength and different paths at the same time. The different wavelengths used here are $\lambda_1 = 1550\,\text{nm}$, $\lambda_2 = 850\,\text{nm}$, $\lambda_3 = 1310\,\text{nm}$, respectively. Laser signal travelling through turbulent atmosphere undergo different amount of intensity fluctuations. The effect of atmospheric turbulence and scintillation causes intensity fluctuation of optical beam thus increasing the outage probability. In this work, wavelength diversity technique is proposed to reduce the turbulence induced fading under both strong and weak atmospheric turbulence condition. The main purpose of this work is to analyse the application of wavelength diversity in FSO to minimize the impact of turbulence on the performance of the link.

As explained earlier wavelength diversity in a FSO framework requires different transmitters and different receivers respectively which we expect it to be M, for each transmitters there will be different wavelength so for M transceivers we allot M wavelengths. For the multiple wavelength channel M, assuming that the outage probability for each of the channels is different, as each of them work on different wavelengths, the total outage probability $P_{out},_m$ of the considered FSO systems corresponds to the probability of outage of all the M links, that is

$$p_{out,m} = \prod_{m=1}^{M} P_{out} \tag{13}$$

By substituting eq. (12) in (13), the total outage probability of POLSK based FSO system with wavelength diversity as

$$p_{out,m} = 1 - \prod_{i=1}^{L} \prod_{j=1}^{O} \left(1 - \prod_{m=1}^{M} \frac{g^2 A}{2} \sum_{K=1}^{\beta} \left(a_k \left[\frac{1}{B} \right]^{\frac{\alpha+K}{2}} G_{2,4}^{3,1} \left(\frac{1}{BA_0 I_l} \sqrt{\frac{SNR_{th}}{\overline{SNR}_{ij}}} \middle| \begin{matrix} 1, 1+g^2 \\ g^2, \alpha, k, 0 \end{matrix} \right) \right) \right) \tag{14}$$

3.3 Time diversity

An alternate approach to wavelength diversity is to use time diversity where identical signals are transmitted in different time slots but fixed wavelength [1550 nm]. Transmissions of the same data take place between a single transmitter and a single receiver. A single wavelength transmission is used in time diversity. The total outage probability of the FSO system using time diversity can be derived based on the assumptions, $\lambda_1 = \lambda_2 = \ldots\ldots = \lambda_m = \lambda$, $\alpha_1 = \alpha_2 = \ldots.\alpha_m = \alpha$ and $\beta_1 = \beta_2 = \ldots.\beta_m = \beta$. By considering the above assumptions on eq. (14), the outage probability of POLSK based FSO system is expressed as

$$p_{out,m} = 1 - \prod_{i=1}^{L} \prod_{j=1}^{O} \left(1 - \left\{ \frac{g^2 A}{2} \sum_{K=1}^{\beta} \left(a_k \left[\frac{1}{B} \right]^{\frac{\alpha+K}{2}} G_{2,4}^{3,1} \left(\frac{1}{BA_0 I_l} \sqrt{\frac{SNR_{th}}{\overline{SNR}_{ij}}} \middle| \begin{matrix} 1, 1+g^2 \\ g^2, \alpha, k, 0 \end{matrix} \right) \right) \right\}^M \right) \tag{15}$$

4 Numerical results and discussions

In the work presented above eqs. (12), (14), (15) are used to calculate outage probability of the FSO link over an M channel with no, wavelength and time diversity scheme, respectively. The outage probability performance for strong atmospheric turbulence ($\alpha = 1, \beta = 2, C_n^2 = 2 \times 10^{-13}\ m^{-2/3}$) and weak atmospheric turbulence ($\alpha = 10, \beta = 5, C_n^2 = 6 \times 10^{-14}\ m^{-2/3}$) have been scrutinized and plotted. The system parameters used here are receiver responsivity (R) = 0.5 A/W, Noise standard deviation $\sigma_n = 10^{-5} A/HZ$ Link length $L_{ij} = 1$ km, power $p_{ij} = 70^{-3}$ watts respectively.

From Figure (3), we can notice that there is an enhancement of nearly 10^{-1} in the performance of outage probability of weak to strong turbulence against SNR for different relay structure parameters (N = 2, M = 3). In Figure (4), we can notice that there is an enhancement of nearly 10^{-4} in the performance of outage probability of weak to strong turbulence against SNR for different relay structure parameters (N = 2, M = 3). But when we compare Figures (3) and (4) by scrutiny we can see that there is an enhancement of nearly 10^{-3} in the performance of outage probability for wavelength to no diversity against SNR for same relay structure parameters (N = 2, M = 3). And for the wavelength diversity case three different wavelengths assumed are $\lambda_1 = 1550$ nm, $\lambda_2 = 850$ nm, and $\lambda_3 = 1310$ nm [16]. Hence we can state that by introducing wavelength diversity the outage performance can be improved to 30 dB accordingly the system performance can be improved. Therefore, implementing wavelength diversity techniques is justified.

In Figure (5), we can notice that there is an enhancement of nearly 10^{-1} in the performance of outage probability of weak to strong turbulence against SNR for different relay structure parameters (N = 2, M = 3). But when we compare Figures (3) and (5) by scrutiny we can see that there is an enhancement of nearly 10^{-1} in the performance of outage probability for time to no diversity against SNR for same relay structure parameters (N = 2, M = 3). And for the time diversity case we fixed operational wavelength as $\lambda = 1550$ nm [16]. But when we compare Figures (4) and (5) we can claim that wavelength is more potent then compares to time diversity.

In Figure (6), outage probability of multi-hop parallel FSO system for No diversity case for the case of weak turbulence including various weather conditions like fog, haze, drizzle and air has been plotted. By scrutiny we see that for SNR = 80 dB outage performance of 10^{-9} for very clear air but 10^{-6} for light fog and 10^{-7} for haze, respectively. It means there is signal deterioration of nearly 20 dB for light fog then compared to very clear air for the same SNR including both serial and parallel relay.

In Figure (7), outage probability of multi-hop parallel FSO system for wavelength diversity case for the case of strong turbulence including various weather conditions like fog, haze, drizzle and air has been plotted. By scrutiny, we see that for SNR = 80 dB outage performance of 10^{-16} for very clear air but 10^{-14} for light fog and 10^{-13} for haze, respectively. It means there is signal deterioration of nearly 20 dB for light fog then compared to very clear air for the same SNR including both serial and parallel relay.

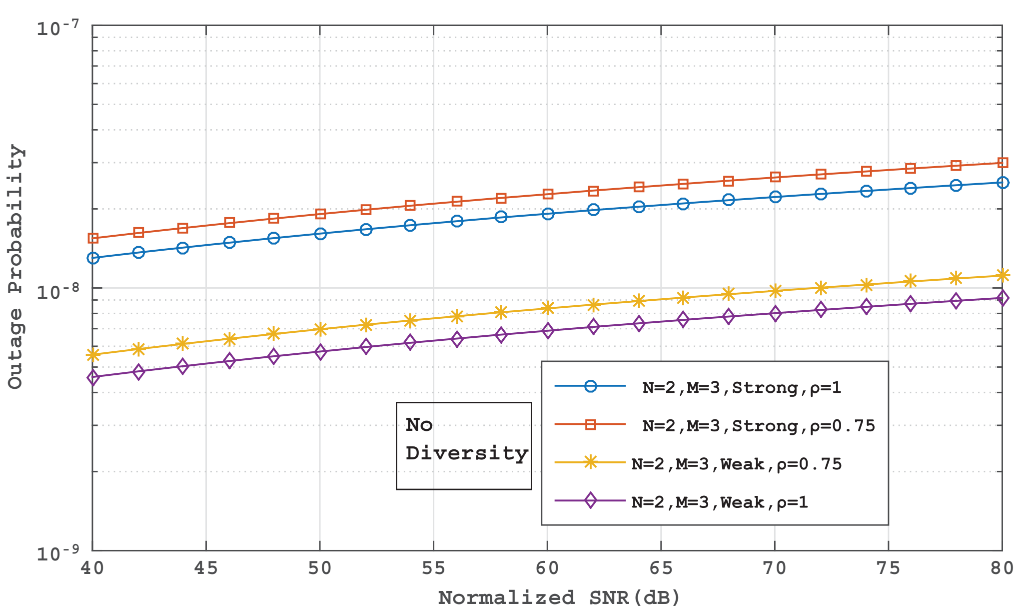

Figure 3: Outage probability of multi-hop parallel FSO system for no diversity case using M distribution model for the case of both weak and strong turbulence conditions.

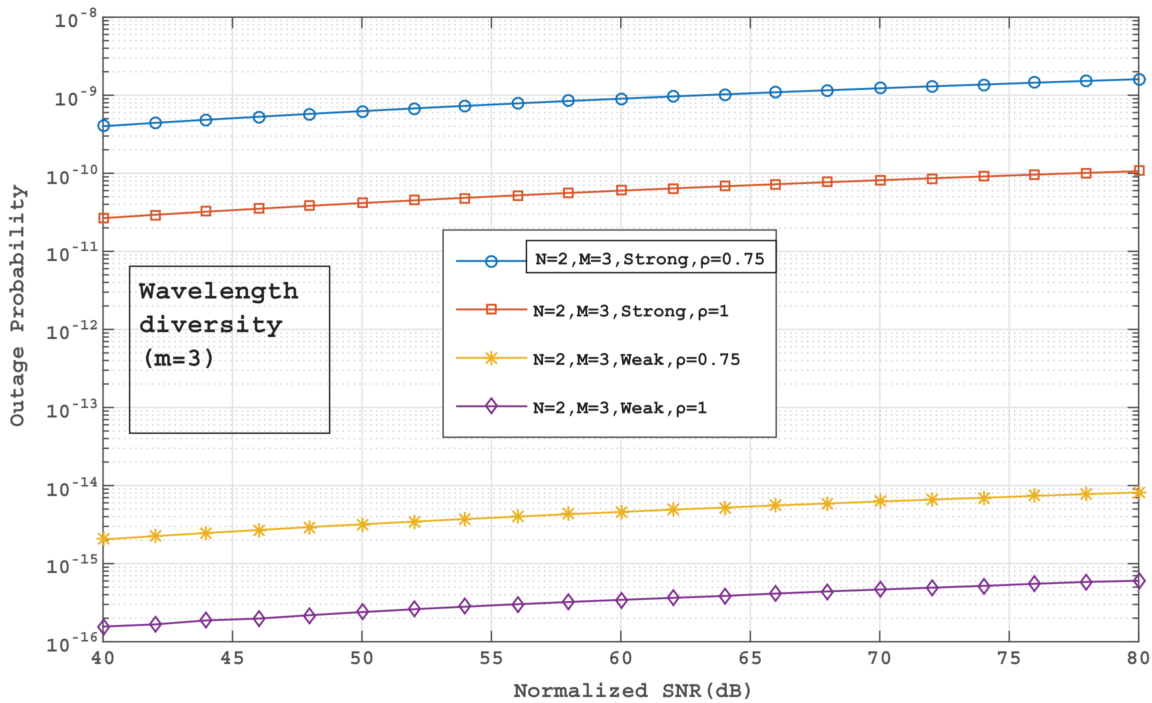

Figure 4: Outage probability of multi-hop parallel FSO system for wavelength diversity case using M distribution model for the case of both weak and strong turbulence conditions [$m = 3$].

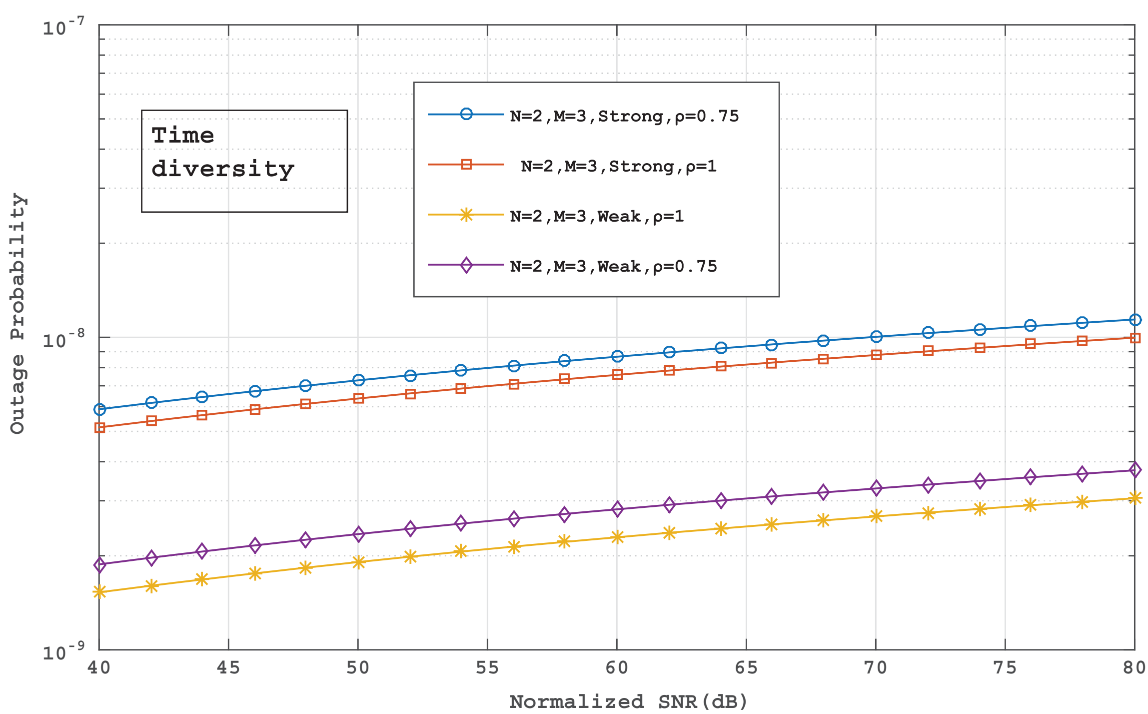

Figure 5: Outage probability of multi-hop parallel FSO system for Time diversity case using M distribution model for the case of both weak and strong turbulence conditions.

Figure (8) outages probability of multi-hop parallel FSO system for wavelength diversity case for the case of strong turbulence including various weather conditions like fog, haze, drizzle and air has been plotted. By scrutiny, we see that for SNR = 80 dB outage performance of 10^{-8} for very clear air but 10^{-7} for light fog and 10^{-6} for haze,

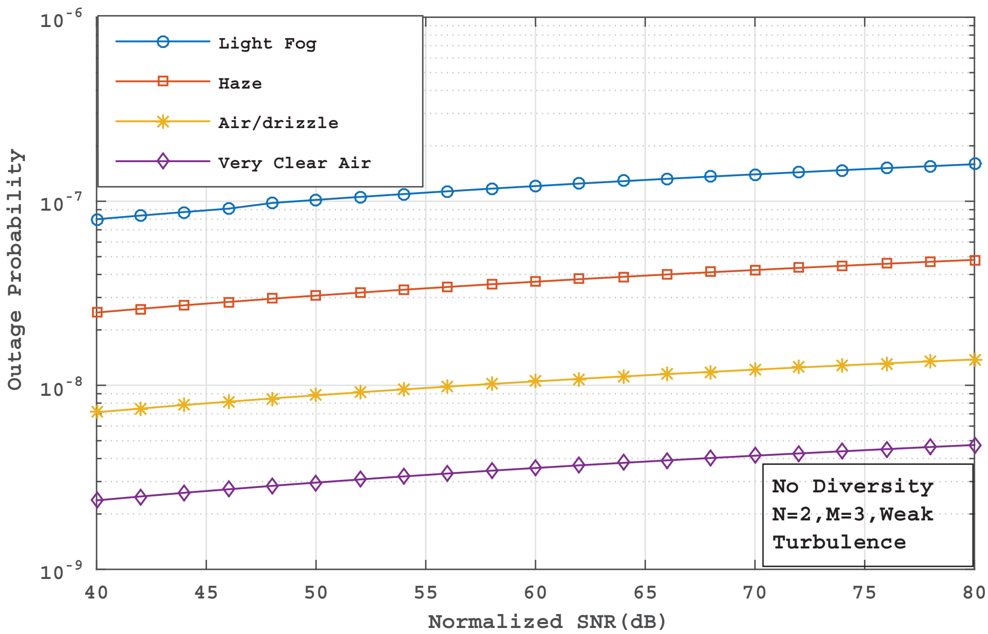

Figure 6: Outage probability of multi-hop parallel FSO system for No diversity case using M distribution model for the case of weak turbulence including weather conditions.

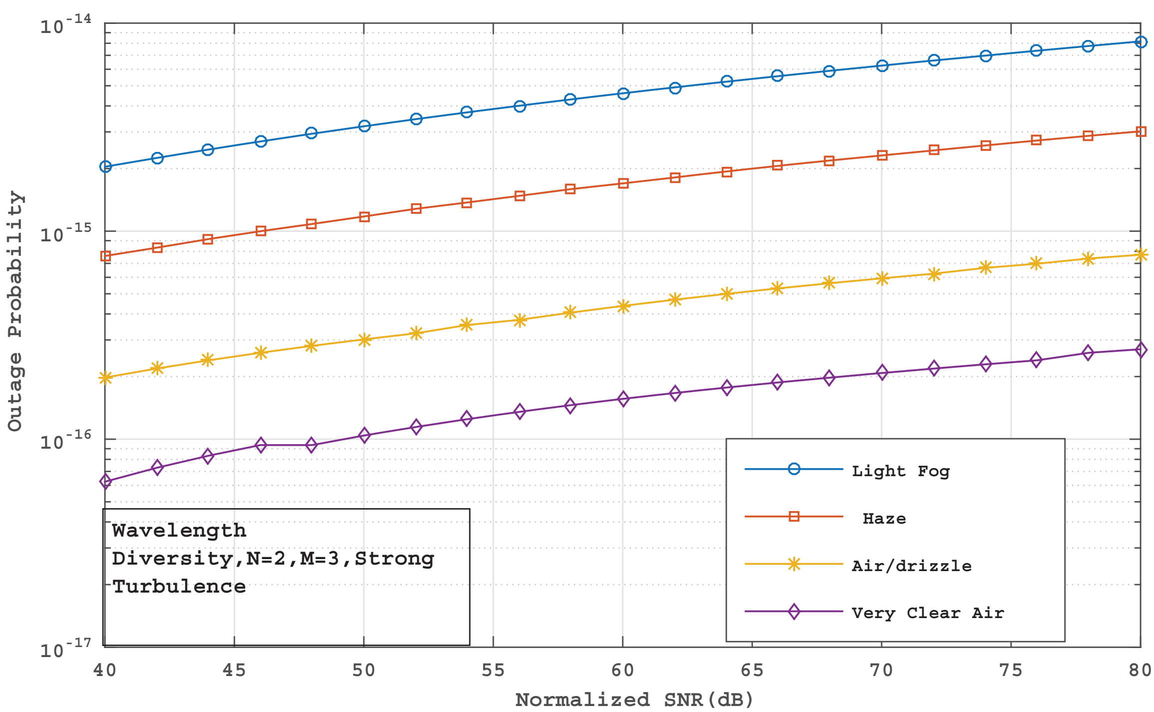

Figure 7: outage probability of multi-hop parallel FSO system for Wavelength diversity case using M distribution model for the case of strong turbulence including weather conditions.

respectively. It means there is signal deterioration of nearly 20 dB for light fog then compared to very clear air for the same SNR including both serial and parallel relay.

5 Conclusions

In this paper, we conclude that to design an efficient and reliable system for long distance communication

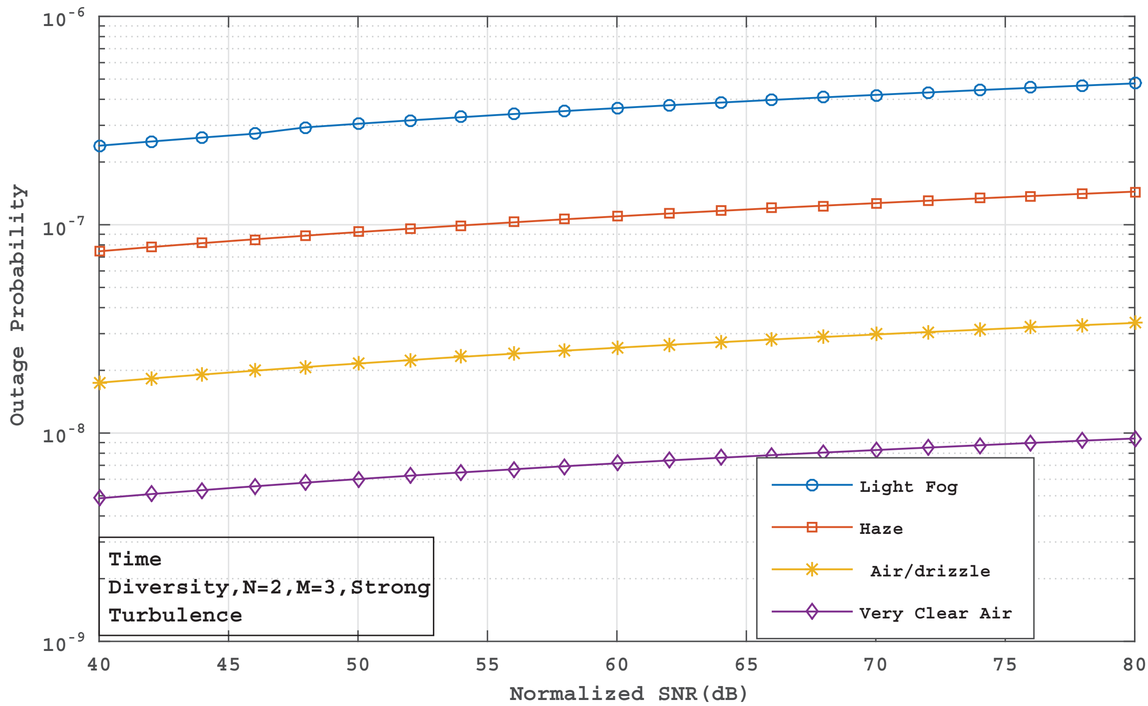

Figure 8: Outage probability of multi-hop parallel FSO system for Time diversity case using M distribution model for the case of strong turbulence including weather conditions.

with less attenuation in spite of atmospheric loss, turbulence, pointing error and weather conditions is to include both serial and parallel relay with structure parameters (M and N) and also by embracing diversity techniques. From the result, we can establish that wavelength diversity provides best performance for fixed structure parameters (N = 2, M = 3).

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