Error Performance of a Cooperative Diversity Mixed FSO/RF System over Gamma-Gamma and Nakagami-M Fading Channels

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***Abstract*—**Atmospheric induced-turbulence is the major challenge suffers by the free space optical (FSO) communication systems in practical deployment. To overcome this limitation, cooperative diversity technique is considered as a prominent solution to improve the system performance. In this paper, we present the error performance of a cooperative diversity AF-based mixed FSO/RF system with direct link over induced-fading channels. The FSO link is characterized by Gamma-Gamma distribution while the RF link is subjected to Nakagami-*m* distribution. Owning to difficulty involves in determining the probability density function (PDF) of the total signal-to-noise ratio (SNR), the moment generating function (MGF) for the total SNR is derived through the lower bound cumulative distribution function (CDF). Utilizing the MGF, the closed-form expression of the average bit error rate (ABER) with a series expansion of the modified Bessel function is then derived for the system. Moreover, the simulation result shows the accuracy of the derived ABER series expression. The effect of atmospheric turbulence under different conditions and the Nakagami-*m* fading parameter are observed on the ABER of the proposed system. The results also illustrate the effectiveness of the parallel relays in enhancing the system performance against fading effect.

***Index Terms*—**Cooperative diversity, gamma-gamma distribution, Nakagami-*m* distribution, moment generating function, average bit error rate

I. Introduction

In the recent times, there has been a growing study in the Free Space Optical (FSO) communication systems in the research community. This is due to the facts that FSO system offers high bandwidth in unregulated spectrum, low cost of deployment, immunity to interference and among others; contrary to RF communication systems [1]-[3]. These makes it appealing for various applications such as last-mile access, backhauling services, data recovery, and high definition transmission and so on [1]. However, upon all this virtues, FSO system is highly susceptible to atmospheric turbulence induced-fading and weather conditions especially over a long distance [4]. Specifically, temperature fluctuations and fog significantly affect the system transmission causing poor reliability and availability for the link and severely degrade the system performance. In addition, misalignment of the beam from its original path commonly known as pointing error due to building sway further deteriorates the FSO system performance and can lead to link outage and failure [5]. In attempt to overcome all the mentioned impairments along the FSO link, cooperative diversity has gained a prominent interest in the recent years. This is a result of its ability to broaden the link coverage area, reduces the need of high power transmitters as well as providing diversity against induced-fading [6]. The concept of cooperative diversity can be employed by either using amplified-and-forward (AF) relaying protocol, or decode-and-forward (DF) relaying protocol. In AF relay, the received signal is only amplified and retransmits to the other nodes without performing any decoding. This type of relay is also called non-regenerative relay. On the other hand, the DF relay known as regenerative relay decodes the received signal and retransmits the copy signal to the other node [7].

Most of the previous researches focused on dual-hop mixed RF/FSO relay systems whereby a single AF or DF relay node is used between the source and the destination over different channel models. Most recently, in [8] and [9] a new scenario of a dual-hop mixed FSO/RF system where FSO link was considered as a broadcast channel or airborne backbone without direct link for multiple users were studied. Also, in [10] and [11] the performance of a DF and AF mixed RF/FSO systems were respectively studied with a direct RF link but only a single relay units is considered for the system. Although, cooperative diversity has been greatly considered in the conventional RF communications, so far [12]-[16]. For instance, in [12] the performance of cooperative diversity AF relay systems over Nakagami-*m* was studied and fixed rate and power transmission were considered for the system. Also, *Nechiporenko et al* studied a cooperative diversity AF system over a Rayleigh fading channels and adaptive transmission techniques were employed. Recently, there have been a few noticeable research of cooperative

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diversity in FSO [14]. *Majid et al* compared the performance of cooperative diversity FSO system with multi-hop FSO system using both AF and DF relay modes [17]. The performance of a cooperative diversity DF mixed RF/FSO system was also studded in [18]. The authors considered selection combining technique at the receiver to select the best relay with highest SIGNAL-to-Noise Ratio (SNR). Moreover, the outage performance of a parallel DF-relay transmission FSO system over a strong turbulence condition was investigated in [19]. To the best of authors' knowledge, cooperative diversity of a mixed FSO/RF system with direct link over induced-fading channels has not been investigated. Motivated by these aforementioned facts in this paper, the error performance of a cooperative diversity AF-based mixed FSO/RF system with maximum ratio combining (MRC) at the destination is presented in this paper. The FSO links undergo Gamma-Gamma distribution fading while the RF link is subjected to Nakagami-*m* distribution. The closed-form expression for the cumulative distribution function (CDF) and moment generating function (MGF) of the total SNR is derived. Utilizing the MGF, the average bit error rate (ABER) for this system is obtained.
The remainder of the paper is structured as follows. In Section II, the cooperative mixed FSO/RF system model is presented. The statistical characteristics of the fading channels are described in Section III. In Section IV, we derive the analytical expressions of the ABER for the cooperative diversity mixed FSO/RF system using MRC combining at the destination. Numerical results and discussions are provided in Section V and finally, concluding remarks are summarized in Section VI.

II. COOPERATIVE SYSTEM MODEL

In this paper, we considered a cooperative wireless system which consist of a direct FSO link between the source (S) and the destination (D) and a parallel dual hop FSO-RF communication links where S communicates with D through $N-$ cooperate AF relay (R) nodes R_k, that is, $(k = 1,2, \dots .N)$ to offer multiple copies of the original signal to the destination as illustrated in Fig. 1. The FSO links that is, $S-R$ and $S-D$ links are assumed to be characterized by Gamma-Gamma distributed turbulence and the RF link $R-D$ is subjected to Nakagami-*m* fading channel. We assumed also that all the channels coefficient are to be mutually independent and non-identical.

The transmission between the S and D occurs in two phases. In first phase, S transmits information signal through the FSO links to the receiving node $q \in \{r, d\}$ by using the subcarrier intensity modulation technique. When the DC component is filtered and the optical-to-electrical conversion is performed, the received signals at the k^{th} relay units and the destination can be expressed as:

$$y_{s,q} = \eta_{s,q} I_{s,q} x + n_{s,q}\,, \quad q \in \{r, d\} \qquad (1)$$

where x is the transmitting signal, $\eta_{s,q}$ is the optical-to-electrical conversion coefficient at the R_k $(\eta_{s,k})$ and destination $(\eta_{s,d})$, $I_{s,q}$ denotes the Gamma-Gamma distribution intensity of the $S-D$ link $(I_{s,d})$ and the $S-R_k$ link $(I_{s,k})$ and $n_{s,q}$ denotes the complex-valued additive white Gaussian noise (AWGN) with zero-mean and variance $\sigma^2_{s,q}$ at the relay and destination. During the second phase, the k^{th} relay amplified the received signal $y_{s,k}$ and transmit it to the destination. At this instance, the system employ time division multiple access (TDMA) mode of transmission, and cause the source to be inactive so as to allow the received information signal to be transmitted from R_k to the destination. The received signal from the R_k at the destination can thus be expressed as:

$$y_{k,d} = G_k h_{k,d} y_{s,k} + n_{k,d}, \;\; k \in \{1, 2, \dots \dots, N\} \qquad (2)$$

where $h_{k,d}$ is the Nakagami-*m* coefficient between the $R_k - D$, G_k denotes the R_k amplifier gain and $n_{k,d}$ represents the AWGN with zero-mean and variance $\sigma^2_{k,d}$.at the destination At the destination, MRC is considered and the total SNR can be obtained as [12, 14]:

$$\gamma_{equ} = \gamma_{s,d} + \sum_{k=1}^{N} \frac{\gamma_{s,k}\gamma_{k,d}}{\gamma_{s,k} + \gamma_{k,d} + 1} \qquad (3)$$

where $\gamma_{s,k} = \eta^2_{s,k} I^2_{s,k} / \sigma^2_{s,k}$ is the instantaneous SNR between S and R_k, $\gamma_{k,d} = h^2_{k,d} / \sigma^2_{k,d}$ is the instantaneous SNR between R_k and D, and $\gamma_{s,d} = \eta^2_{s,d} I^2_{s,d} / \sigma^2_{s,d}$ is the instantaneous SNR between S and D. Thus, the total SNR given in (3) at the destination can be approximated by its upper bound as it is quite proven to be accurate in [12] as:

$$\gamma_{equ} \le \gamma_{s,d} + \sum_{k=1}^{N} \gamma_k \; = \gamma_{ub} \qquad (4)$$

where $\gamma_k = min(\gamma_{s,k}, \gamma_{k,d})$

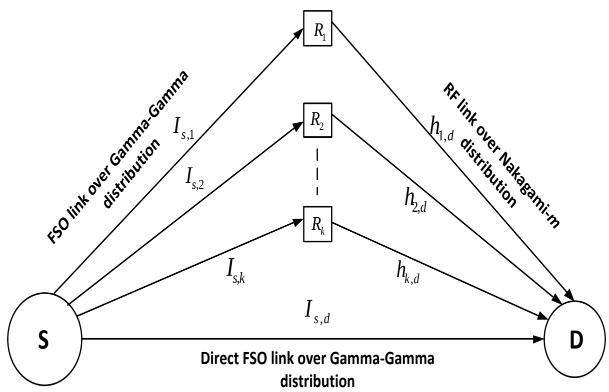

Fig. 1. Cooperative diversity Mixed FSO/RF system

III. STATISTICAL CHANNEL MODELS

In this work, the FSO links are considered to be subjected to Gamma-Gamma induced–fading distribution. The model is valid over a wide range of turbulence conditions (weak to strong) and it was found to yield an excellent fit experimental data [20]. The probability density function (PDF) for the Gamma-Gamma distribution can be expressed as [21], [22]:

$$f_I(I) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{\alpha+\beta}{2}-1} K_{\alpha-\beta}\left(2\sqrt{\alpha\beta I}\right), \quad I > 0 \quad (5)$$

where $\Gamma(.)$ and $K_v(.)$ are defined as gamma function and v^{th} order modified Bessel function of the second kind respectively, α and β are scintillation parameters related to Rytov variance which are defined as the effective number of large scale and small scale eddies respectively, and thus are specified as [21]:

$$\begin{cases} \alpha = \left[exp\left(\dfrac{0.49\sigma_R^2}{\left(1+1.11\sigma_R^{12/5}\right)^{7/6}} \right) - 1 \right]^{-1} \\ \beta = \left[exp\left(\dfrac{0.51\sigma_R^2}{\left(1+0.69\sigma_R^{12/5}\right)^{5/6}} \right) - 1 \right]^{-1} \end{cases} \quad (6)$$

Using the series expansion of the Bessel modified function of second kind defined in [23, Eq. (10)] as:

$$K_v(x) = \frac{\pi}{2\sin(\pi v)} \sum_{j=0}^{\infty} \left[\frac{1}{\Gamma(j-v+1)j!} \left(\frac{x}{2}\right)^{2j-v} - \frac{1}{\Gamma(j+v+1)j!} \left(\frac{x}{2}\right)^{2j+v} \right] \quad (7)$$

Thus, the Gamma-Gamma PDF of FSO link can be defined in series form as:

$$f_{I_{s,q}}(I) = \sum_{j=0}^{\infty} \left[x_j(\alpha,\beta) I^{j+\beta-1} + x_j(\beta,\alpha) I^{j+\alpha-1} \right] \quad (8)$$

where,

$$x_j(\alpha,\beta) = \frac{\pi(\alpha\beta)^{j+\beta}\Gamma(\alpha-\beta)\Gamma(1-\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)\Gamma(j-\alpha+\beta+1)j!}$$

Since $\gamma_{s,q} = \eta_{s,q}^2 I_{s,q}^2 / \sigma_{s,q}^2$, then, $I_{s,q} = \sqrt{\gamma_{s,q}/\bar{\gamma}_{s,q}}$. Thus, by power transformation, (8) can be rewritten in terms of SNR as:

$$f_{\gamma_{s,q}}(\gamma) = \frac{1}{2} \sum_{j=0}^{\infty} \left[x_j(\alpha,\beta) \left(\frac{\gamma}{\bar{\gamma}_{s,q}}\right)^{j+\beta} \gamma^{-1} + x_j(\beta,\alpha) \left(\frac{\gamma}{\bar{\gamma}_{s,q}}\right)^{j+\alpha} \gamma^{-1} \right] \quad (9)$$

where $\bar{\gamma}_{s,q}$ is the average SNR between the source and the receiving node $q \in \{r, d\}$

The lower bound CDF of the FSO links can be derived by integrating the link PDF as:

$$F_\gamma(\gamma) = \int_0^\infty f_\gamma(\gamma) d\gamma \quad (10)$$

By putting (9) into (10), the CDF for the FSO links can be expressed as:

$$F_{\gamma_{s,q}}(\gamma) = \sum_{j=0}^{\infty} \left[\frac{x_j(\alpha,\beta)}{j+\beta} \left(\frac{\gamma}{\bar{\gamma}_{s,q}}\right)^{\frac{j+\beta}{2}} + \frac{x_j(\beta,\alpha)}{j+\alpha} \left(\frac{\gamma}{\bar{\gamma}_{s,q}}\right)^{\frac{j+\alpha}{2}} \right] \quad (11)$$

On the other hand, the RF link between the R_k relay and the destination is subjected to Nakagami-m distribution and the PDF can be defined as [1, 24]:

$$f_{\gamma_{k,d}}(\gamma) = \left(\frac{m}{\bar{\gamma}_{k,d}}\right)^m \frac{\gamma^{m-1}}{\Gamma(m)} exp\left(-\frac{m\gamma}{\bar{\gamma}_{k,d}}\right) \quad (12)$$

where $\bar{\gamma}_{k,d}$ is the average SNR between the R_k relay and the destination and m is the Nakagami-*m* fading parameter of the RF link

By substituting (12) into (10), the CDF of the RF link can be expressed as:

$$F_{\gamma_{k,d}}(\gamma) = \int_0^\infty \left(\frac{m}{\bar{\gamma}_{k,d}}\right)^m \frac{\gamma^{m-1}}{\Gamma(m)} exp\left(-\frac{m\gamma}{\bar{\gamma}_{k,d}}\right) d\gamma \quad (13)$$

Applying the integral identity given in [25, Eq. (3.351(1))], the lower bound CDF of the RF link over Nakagami-*m* can be obtained as:

$$F_{\gamma_{k,d}}(\gamma) = \frac{1}{\Gamma(m)} \gamma\left(m, \frac{m\gamma}{\bar{\gamma}_2}\right) \quad (14)$$

where, $\gamma(s,x)$ is the lower incomplete Gamma function

IV. ERROR RATE PERFORMANCE ANALYSIS

In this study, the M-PSK modulation scheme is considered for the system and the average BER for this modulation scheme can be expressed as [26]:

$$P_b = A \int_0^\infty \int_0^\infty Q\left(\sqrt{2(\gamma_{s,d}+\gamma_k)}B\right) \times f_{\gamma_{s,d}}(\gamma_{s,d}) f_{\gamma_k}(\gamma_k) d\gamma_{s,d} d\gamma_k \quad (15)$$

where $A = 1$, $B = 1$ when $M = 2$ for BPSK and $A = 2/log_2(M)$, $B = sin(\pi/M)$ for $M > 2$

It is very difficult, if not impossible, to obtain the closed-form expression for (15). As a result of this, the approximate Q-function defined in [27] is employed and the average BER for the system is obtained as:

$$P_b = \frac{A}{12} M_{\gamma_{ub}}(B^2) + \frac{A}{4} M_{\gamma_{ub}}\left(\frac{4B^2}{3}\right) \quad (16)$$

where $M_{\gamma_{ub}}(.)$ is the moment generating function (MGF) defined as [12, 14]:

$$M_{\gamma_{ub}}(s) = M_{\gamma_{s,d}}(s) \prod_{k=1}^{N} M_{\gamma_k}(s) \tag{17}$$

where $M_{\gamma_{s,d}}(s)$ and $M_{\gamma_k}(s)$ are the MGF of $\gamma_{s,d}$ and γ_k respectively, and can be defined as [3]:

$$M_X(s) = s\int_0^\infty e^{-sX} F_X(X) dX \tag{18}$$

By substituting (11) into (18) and then apply the integral identity defined in [25, Eq. (3.381(4))], the $M_{\gamma_{s,d}}(s)$ for the direct link (S-D) can be obtained as in (19).

$$M_{\gamma_{s,d}}(s) = s\sum_{j=0}^{\infty}\left[\frac{x_j(\alpha,\beta)\Gamma\left(\frac{j+\beta+2}{2}\right)}{(j+\beta)(s)^{\frac{j+\beta+2}{2}}}\left(\bar{\gamma}_{s,d}\right)^{-\left(\frac{j+\beta}{2}\right)} + \frac{x_j(\beta,\alpha)\Gamma\left(\frac{j+\alpha+2}{2}\right)}{(j+\beta)(s)^{\frac{j+\alpha+2}{2}}}\left(\bar{\gamma}_{s,d}\right)^{-\left(\frac{j+\alpha}{2}\right)}\right] \tag{19}$$

In addition, the $M_{\gamma_k}(s)$ for the cooperative link can be determined through the lower-bound CDF of the γ_k by using (11) and (14) as follows:

$$F_{\gamma_k}(\gamma) = P(\gamma_{s,k} > \gamma)\, P(\gamma_{k,d} > \gamma) \;\; for\; k = 1, 2, \ldots, N$$

$$\triangleq \frac{1}{\Gamma(m)}\gamma\left(m, \frac{m\gamma}{\bar{\gamma}_{k,d}}\right)\sum_{j=0}^{\infty}\left[\frac{x_j(\alpha,\beta)}{j+\beta}\left(\frac{\gamma}{\bar{\gamma}_{s,k}}\right)^{\frac{j+\beta}{2}} + \frac{x_j(\beta,\alpha)}{j+\alpha}\left(\frac{\gamma}{\bar{\gamma}_{s,k}}\right)^{\frac{j+\alpha}{2}}\right] \tag{20}$$

If it is assumed from (20) that $\bar{\gamma}_{s,k} = \bar{\gamma}_{k,d} = \mu_k$, then, by substituting (20) into (18), the $M_{\gamma_k}(s)$ can be expressed as:

$$\begin{aligned} M_{\gamma_k}(s) = \frac{s}{\Gamma(m)}\sum_{j=0}^{\infty}\Bigg[&\frac{x_j(\alpha,\beta)}{j+\beta}(\mu_k)^{-\left(\frac{j+\beta}{2}\right)}\int_o^\infty e^{-s\gamma}\gamma^{\frac{j+\beta}{2}}\gamma\left(m,\frac{m\gamma}{\mu_k}\right)d\gamma \\ &+ \frac{x_j(\beta,\alpha)}{j+\alpha}(\mu_k)^{-\left(\frac{j+\alpha}{2}\right)}\int_0^\infty e^{-s\gamma}\gamma^{\frac{j+\alpha}{2}}\gamma\left(m,\frac{m\gamma}{\mu_k}\right)d\gamma\Bigg] \end{aligned} \tag{21}$$

$$\begin{aligned} M_{\gamma_k}(s) = \frac{s}{\Gamma(m)}\sum_{j=0}^{\infty}\Bigg[&\frac{x_j(\alpha,\beta)\Gamma\left(\frac{j+\beta+2+2m}{2}\right)}{(j+\beta)\left(\frac{m}{\mu_k}+s\right)^{\frac{j+\beta+2+2m}{2}}}\left(\frac{m}{\mu_k}\right)^m(\mu_k)^{-\left(\frac{j+\beta}{2}\right)}{}_2F_1\left(1,\tfrac{j+\beta+2+2m}{2};m+1;\tfrac{m}{m+s\mu_k}\right) \\ &+ \frac{x_j(\beta,\alpha)\Gamma\left(\frac{j+\alpha+2+2m}{2}\right)}{(j+\beta)\left(\frac{m}{\mu_k}+s\right)^{\frac{j+\alpha+2+2m}{2}}}\left(\frac{m}{\mu_k}\right)^m(\mu_k)^{-\left(\frac{j+\alpha}{2}\right)}{}_2F_1\left(1,\tfrac{j+\alpha+2+2m}{2};m+1;\tfrac{m}{m+s\mu_k}\right)\Bigg] \end{aligned} \tag{22}$$

$$\begin{aligned} M_{\gamma_k}(s) = \frac{sm^{m-1}}{\Gamma(m)}\sum_{j=0}^{\infty}\Bigg[&\frac{x_j(\alpha,\beta)\Gamma\left(\frac{j+\beta+2+2m}{2}\right)}{(j+\beta)\left({}^{m}/_{\mu_k}+s\right)^{\frac{j+\beta+2+2m}{2}}}(\mu_k)^{-\left(\frac{j+\beta+2m}{2}\right)}G_{2,2}^{1,2}\left(-\frac{m}{m+s\mu_k}\middle|\begin{matrix}0, & -m-\left(\frac{j+\beta}{2}\right)\\ 0, & -m\end{matrix}\right) \\ &+ \frac{x_j(\beta,\alpha)\Gamma\left(\frac{j+\alpha+2+2m}{2}\right)}{(j+\beta)\left({}^{m}/_{\mu_k}+s\right)^{\frac{j+\alpha+2+2m}{2}}}(\mu_k)^{-\left(\frac{j+\alpha+2m}{2}\right)}G_{2,2}^{1,2}\left(-\frac{m}{m+s\mu_k}\middle|\begin{matrix}0, & -m-\left(\frac{j+\alpha}{2}\right)\\ 0, & -m\end{matrix}\right)\Bigg] \end{aligned} \tag{23}$$

Applying the integral identity defined in [25, Eq. (6.4555(1))], the MGF can then be obtained as in (22) with $2F_1(a, b; c; d)$ defined as the hypergeometric function. By using the identity defined in [25, Eq. (9.34(7))], the (22) can therefore be converted to Meijer-G function term as in (23).

Finally, the average BER for the proposed cooperative diversity mixed FSO/RF system can be obtained by substituting (17) into (16) through the use of (19) and (23).

V. Numerical Results and Discussions

In this section, we present and discuss the numerical results for the average BER performance of the proposed cooperative diversity mixed FSO/RF system using the derived expression. The FSO link experiences Gamma-

Gamma fading turbulence and the turbulence parameters set for the distribution are $(\alpha = 3.78, \beta = 3.74)$, $(\alpha = 2.50, \beta = 2.06)$ and $(\alpha = 2.04, \beta = 1.10)$ respectively for weak, moderate and strong turbulence conditions. The exact ABER has been verified by Monte Carlo simulation which is obtained by taking the finite terms with $p = 50$ in the series solution. In addition, without loss of generality, we assumed the same average SNRs for all the links.

Fig. 2 illustrates the performance of the proposed system under the influence of turbulence conditions. The BPSK cooperative diversity system is considered to have two parallel relay units ($N = 2$) and its performance is compared with the direct FSO link system without any relay node. It can be observed that the stronger the atmospheric turbulence, the more the systems ABER performance deteriorates with the cooperative diversity system offers the better error rate. For instance, at average SNR of 20dB under the strong turbulence condition, the direct link performance is poor with error rate of 1.07×10^{-1} compare with 8.05×10^{-4} produce by cooperative diversity system. It can also be deduced from the result that the derived series analytical ABER result agreed with simulation result which shows the accuracy of closed-form expression.

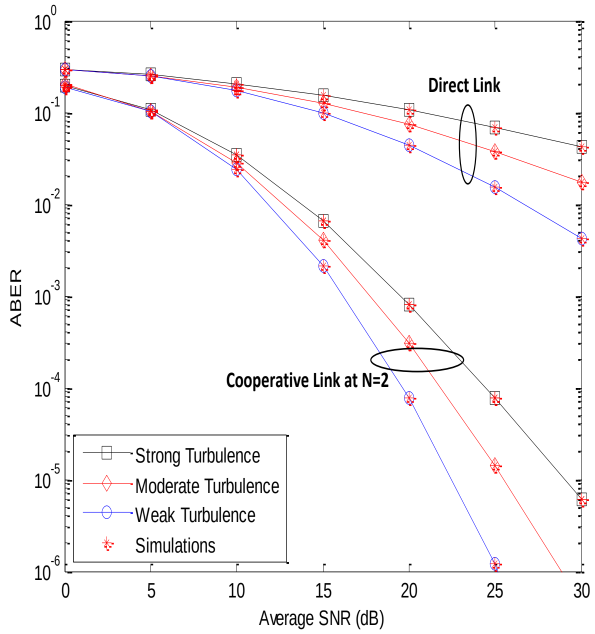

Fig. 2. Performance of the proposed BPSK cooperative diversity system under various turbulence conditions when $m = 2$, $N = 2$

The effect of number of parallel relay nodes employ between the source and the destination under strong and moderate turbulence conditions is presented in fig. 3. As expected, the increase in the parallel relay nodes the better the system ABER performance. It can be seen that the system with $N = 3$ relay nodes offers the best performance under the same channel condition. This is also proved further in fig. 4 that the system with higher number of parallel relay nodes offers lower error rate over a long transmission distance compared with direct link without relay node. For instance, for instance, at $1500\,m$, the cooperative system with $N = 3$ relay node yeids 2.01×10^{-7} errors compared with when $N = 0$ that offer 5.26×10^{-1} errors. It can also be deduced from figure 4 that the system ABER deteriorates with the increase in link distance and it becomes less pronounced at the distance of $2000\,m$ where there is no significant change in error.

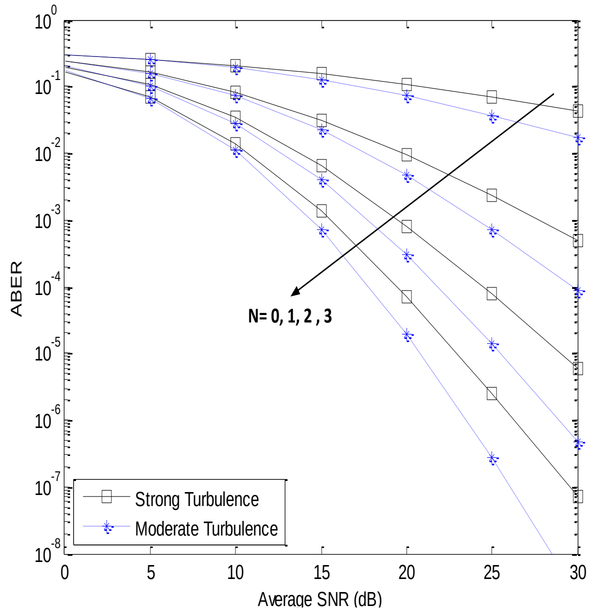

Fig. 3 Effect of number of parallel relay on the system performance under strong turbulence at $m = 0.5$ when BPSK is considered

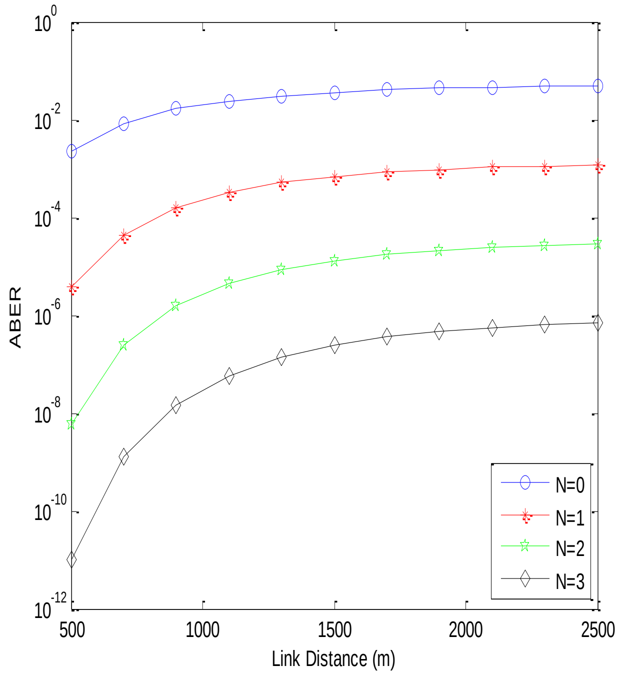

Fig. 4 The performance of the proposed system for different relay N over link distance at average $SNR = 25$ when $m = 0.5$

In fig. 5, the average BER for the cooperative system with different M-PSK modulation schemes is presented under the strong turbulence condition when $N = 2$ and $m = 0.5$. It can be seen from the result that BPSK offers the best performance as compared with others modulation schemes. Comparing BSPSK with 16-PSK at average SNR of $15dB$, for instance, the BSPK yields error of 3.9×10^{-3} as compared with 0.7×10^{-1} error rate produce by 16-PSK under the same turbulence performance.

The performance of cooperative diversity system under different fading and turbulence parameters is illustrated in fig. 6. It can be deduced that the degradation in the error rate increases with the unified effect of turbulence and RF fading parameters. The effect of turbulence in FSO link on the ABER of the system is more intense when the RF link fading parameter is lower as compared to the scenario when the fading parameter is higher. For instance, at $SNR = 20dB$ under strong condition when $m = 3$, the ABER is 6.89×10^{-6} and it increases to 8.15×10^{-4} when $m = 0.5$.

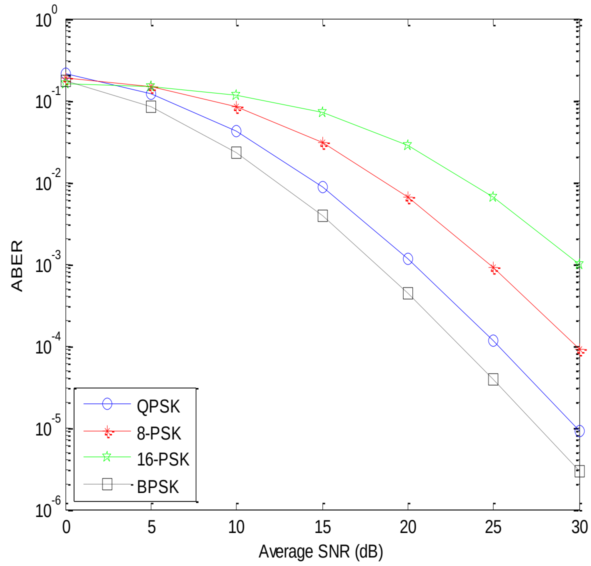

Fig. 5 Performance comparison between different M-PSK under strong turbulence when $N = 2$ and $m = 0.5$

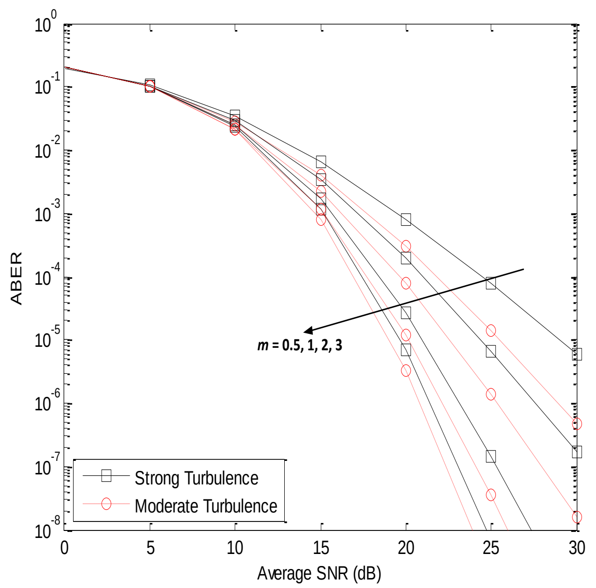

Fig. 6 Error performance of the BPSK cooperative diversity system for different fading and turbulence parameters at $N = 2$

VI. Conclusion

In this paper, power series based ABER for the cooperative diversity mixed FSO/RF system has been derived through the MGF of the system total SNR. The FSO link and RF link are respectively subjected to Gamma-Gamma and Nakagami-*m* distribution. The effective of turbulence and number of parallel rely nodes on the system error rate have been investigated. The derived series analytical expression for the error rate matched the simulation result. The result shows that the system performance can be improved under the fading channels by increasing the number of the parallel relay nodes between the source and the destination.

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