On the Performance of Hybrid RF/FSO Relay Algorithms for 5G Wireless Communication Systems

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Abstract

Currently, free space optical (FSO) communication systems have become very popular because of its high achievable optical bandwidth, greater security against eavesdropping, low power consumption. In this paper, the authors have considered decode and forward (DF) Relay based dual hop hybrid radio frequency (RF) and FSO (RF/FSO) system. Where, RF link is modeled as Rayleigh faded distribution and FSO link is modeled as α-μ distributed channel. A closed form expression of outage probability is derived for the proposed system. The effect of the channel parameters on the outage performance is also studied. *Furthermore, we have also analyzed the asymptotic behavior of proposed analysis in high signal to noise ratio (SNR) regime. The analytical results are well aligned with asymptotic results, which shows the correctness of proposed analysis.*

Keywords: RF/FSO, Relay, Decode and forward, α-μ distribution, outage probability, Asymptotic analysis

1. Introduction

Wireless communication systems have gained lots of popularity in last two decades because of their ability to provide mobile access and unbounded connectivity. However, performance of wireless communication systems is degraded due to path loss, shadowing, and multipath fading effects. In multi-path fading phenomenon, two or more than two radio signals reaching at receiver by paths which arrives at slightly different times. These radio signals are called multi path signals, combined at the receiver. The resultant received signal can vary widely in terms of amplitude and phase [1]. The shadowing effect [2] is caused due to power absorption by obstacles present between the transmitting and receiving nodes. The path loss [1] is happened because of power dissipation effects of the propagation channel. Although, diversity combing using multiple antennas is one of the very popular techniques to mitigate deteriorative effect of multipath fading. Then also, due to the limitations of size and cost of wireless devices in sensor and cellular networks, placing multiple antennas on a single wireless node may not be practically possible. In such cases, cooperating with other nodes to form a distributed antenna system (DAS) becomes a more promising and desirable solution. This can be achieved using cooperative communications, where an intermediate node is place between transmitting and receiving node which is called relay. FSO Communication [2-11] uses optical carrier to convey information from one point to other through free space unguided channels. Due to its properties *i.e.* extremely high bandwidth, easy to deploy, unlicensed spectrum, low power consumption, reduced size and improved channel security, it is considered as an extension of frontier for high speed broadband connection. Secondary benefits of FSO systems are

as: (i) easily expandable, (ii) light weight and compact in size, (iii) quick deploy ability, and (iv) can be deployed at places where optic fiber cables cannot be used. In [12-20] cooperative communication based free space optical (FSO) system has been studied. In [19], log-normal distribution is introduced to model the weak atmospheric turbulence in the FSO links. However, authors have been adopted the Gamma-Gamma distribution to represent wide range of atmospheric turbulence conditions (weak to strong). Authors in [12-17] have proposed a cooperative diversity technique to mitigate the effect of fading over the radio frequency (RF) channel. In [13, 17-20], outage performance is analyzed over weak, moderate and strong turbulence. Relay-aided FSO system is analyzed by Wang *et. al* in [21]. Performance metrics is very important to monitor any system's operation, and so metrics such as BER outage probability become very useful. Point-to-point transmission has been analyzed in the past but according to authors, when the distance between transmitters and receivers is increased in kilometers, then relay operation must be utilized. Wang *et. al.,* have analyzed relay assisted network for serial and parallel transmission. Outage probability has been calculated and plotted against transmitted power. In order to compare relay FSO with direct transmission system, authors have also evaluated outage probability for directly connected (or P2P) FSO systems. Polarization has been opted as modulation technique in FSO systems [22]. Tang *et. al* have reported coherent binary polarization shift keying (BOLSK) for reduction of BER in turbulence effected FSO systems. When larger receiver apertures are replaced by several smaller apertures, received wave front becomes coherent, thus increasing reception quality. Based on this fact, authors have proposed BOLSK-MIMO FSO system. In the aforementioned literature, the outage probability and bit error rate (BER) performance is analyzed for one-way relaying (OWR). The spectral efficiency of the system can further be improved by using two-way relay (TWR) in place of OWR. In [23], authors have proposed two relay selection for multi relay FSO network. Yacoub in [24], proposed α-µ distributed random variable includes several distributions as special cases such as Nakagami-m, Rayleigh and Weibull distribution. Peppas [25] demonstrates the utilization of α-µ distribution as a general fading model for FSO systems. In this paper, we have analyzed the outage performance analysis for decode and forward relay scheme over asymmetric RF/FSO fading channel. The rest of paper is arranged as follows: Section II describes proposed system model. In Section III, a closed form expressions of outage probability (OP) is derived. Numerical results are discussed in Section IV and finally the paper is concluded and summarized in Section V.

2. System Model

In this research work, we consider dual hop decode and forward relay network as illustrated in Figure 1. For given scenario, in first hop, data is transmitted between source node S and relay node R. While in second hop, relay node R decodes the received signal from S and forwards to destination D. Considering there is no direct link between S and D. The fading characteristics of the S-R link is modeled as Rayleigh distribution where the received signal at the relay node is expressed as
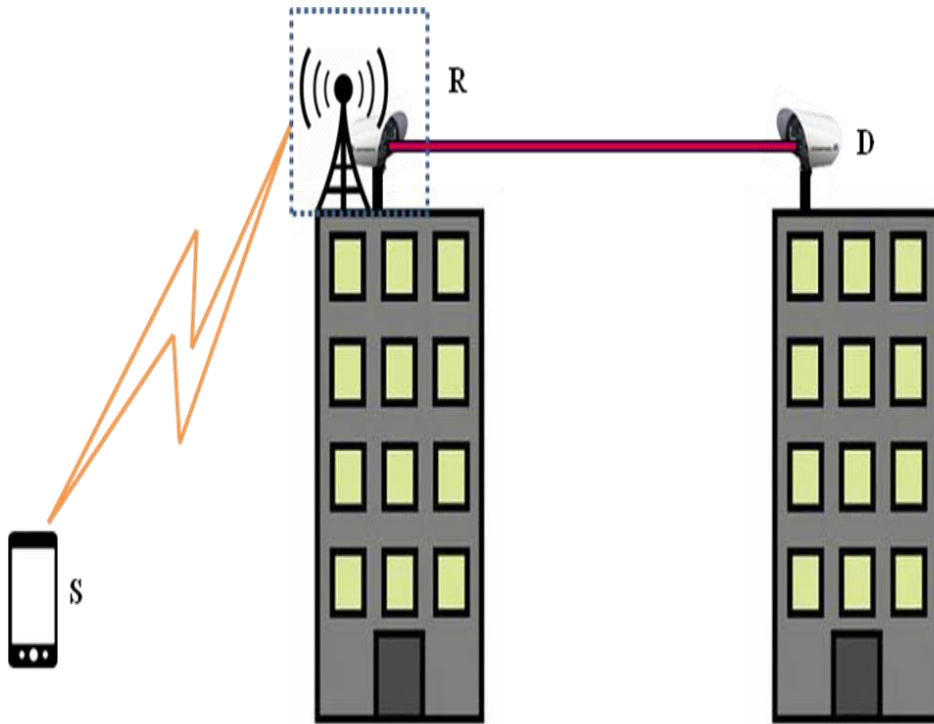
$$r = \alpha_1 x + n_1 \qquad (1)$$

where α_1 is Rayleigh fading coefficient, x is the signal input at relay node and n_1 is additive white Gaussian noise (AWGN).

The probability density function (PDF) of Rayleigh fading channel in terms of instantaneous SNR can be expressed as

$$f_{SR}(\gamma) = \frac{1}{\gamma_{SR}} \exp\left(-\frac{\gamma}{\gamma_{SR}}\right) \qquad (2)$$

Where $\overline{\gamma}_{SR}$ is the average SNR between S-R link.

Figure 1. System Model

On the other hand, the probability density function (pdf) of the R-D link has been modelled as α-μ distributed random variable, as given by [24]

$$f_{RD}(\gamma) = \frac{\alpha\mu^\mu\gamma^{\left(\frac{\alpha\mu}{2}-1\right)}}{2\Gamma(\mu)\overline{\gamma}_{RD}} \exp\left(-\mu\left(\frac{\gamma}{\overline{\gamma}_{RD}}\right)^{\frac{\alpha}{2}}\right)$$

(3)

where α is an arbitrary fading parameter, μ is the inverse of the normalized variance defined as [13]

$$\mu = \frac{E^2[R_\alpha]}{V[R_\alpha]}$$

where E and V are the expectation and the variance operators, respectively.

3. Outage Probability Analysis

Outage probability (OP) is an important performance evaluation metric, OP, measures the probability of failing to achieve an output SNR threshold required for a desired service. In this section, the performance of proposed system is evaluated in terms of outage probability (OP). The outage probability can be expressed [8], as:

$$P_{out} = P_r\{\min(\gamma_{SR}, \gamma_{SD}) < \gamma_{th}\}$$
$$= F_{SR}(\gamma_{th}) + F_{RD}(\gamma_{th}) - F_{SR}(\gamma_{th})F_{RD}(\gamma_{th}) \tag{4}$$

where $F(\circ)$ represents Cumulative density function.

$$F_{SR}(\gamma_{th}) = \int_0^{\gamma_{th}} f_{SR}(\gamma)\,d\gamma \tag{5}$$

By substituting of sin (5), The above integration can be expressed as

$$F_{SR}(\gamma_{th}) = \frac{1}{\overline{\gamma}_{SR}} \int_0^{\gamma_{th}} \exp\left(-\frac{\gamma}{\overline{\gamma}_{SR}}\right) d\gamma \tag{6}$$

After some mathematical manipulation, the above integral can be written as

$$F_{SR}(\gamma_{th}) = 1 - \exp\left(-\frac{\gamma_{th}}{\overline{\gamma}_{SR}}\right) \tag{7}$$

Similarly, as above, by su

$$F_{RD}(\gamma_{th}) = \frac{\alpha\mu^{\mu}}{2\Gamma(\mu)\overline{\gamma}_{RD}} \int_0^{\gamma_{th}} \gamma^{\left(\frac{\alpha\mu}{2}-1\right)} \exp\left(-\mu\left(\frac{\gamma}{\overline{\gamma}_{RD}}\right)^{\frac{\alpha}{2}}\right) d\gamma$$

The above expression can be solved using [26, (3.381.8)], The resultant expression can be written as:

$$F_{RD}(\gamma_{th}) = \frac{1}{\Gamma(\mu)} \gamma\left(\mu, \left(\frac{\gamma_{th}}{\overline{\gamma}_{RD}}\right)^{\frac{\alpha}{2}}\right) \tag{8}$$

where $\gamma(\circ)$ represents the lower incomplete gamma function as given in [15].

By substituting value from equation (7) and (8) in equation (4), The resultant value of outage probability (P_{out}) can be written as:

$$P_{out} = 1 - \exp\left(-\frac{\gamma_{th}}{\overline{\gamma}_{SR}}\right) + \frac{1}{\Gamma(\mu)} \gamma\left(\mu, \left(\frac{\gamma_{th}}{\overline{\gamma}_{RD}}\right)^{\frac{\alpha}{2}}\right) - \frac{1}{\Gamma(\mu)}\left(1 - \exp\left(-\frac{\gamma_{th}}{\overline{\gamma}_{SR}}\right)\right) \gamma\left(\mu, \left(\frac{\gamma_{th}}{\overline{\gamma}_{RD}}\right)^{\frac{\alpha}{2}}\right) \tag{9}$$

4. Asymptotic Analysis

In order to get better insight of attained expression of outage probability. Asymptotic expression of in outage probability in high SNR ($\overline{\gamma} \to \infty$) has been derived. The expression of outage probability in high SNR, equation (4) can be expressed as [27]

$$P_{out}(\gamma_{th}) \approx F_{SR}(\gamma_{th}) + F_{RD}(\gamma_{th}) \qquad (10)$$

By putting $\bar{\gamma}_{RD} = \bar{\gamma}_{SD} = \bar{\gamma}$ and setting $\bar{\gamma} \to \infty$,

From equation (7), $F_{SR}(\gamma_{th}) = 1 - \exp\left(-\dfrac{\gamma_{th}}{\bar{\gamma}}\right) \to 0$ for $\bar{\gamma} \to \infty \qquad (11)$

Similarly from equation (8), $F_{RD}(\gamma_{th}) = \dfrac{1}{\Gamma(\mu)} \gamma\left(\mu, \left(\dfrac{\gamma_{th}}{\bar{\gamma}}\right)^{\frac{\alpha}{2}}\right)$ for $\bar{\gamma} \to \infty$ and using

the equation from [26, (8.354.1)] and neglecting higher order terms, the above equation can be expressed as :

$$F_{RD}(\gamma_{th}) = \frac{1}{\Gamma(\mu)}\left(\frac{\gamma_{th}}{\bar{\gamma}}\right)^{\frac{\alpha\mu}{2}} \qquad (12)$$

By substituting results, from equation (11) and equation (12) in equation (10), the resultant expression of outage probability can be expressed as :

$$P_{out}(\gamma_{th}) = \frac{1}{\Gamma(\mu)}\left(\frac{\gamma_{th}}{\bar{\gamma}}\right)^{\frac{\alpha\mu}{2}} \qquad (13)$$

5. Results and Discussion

In this section, the analytical results for the outage probability for the DF based dual hop hybrid RF/FSO system, without considering the pointing error has been discussed. Here RF link is modeled as Rayleigh distribution and the FSO link is modeled as α-μ distribution.
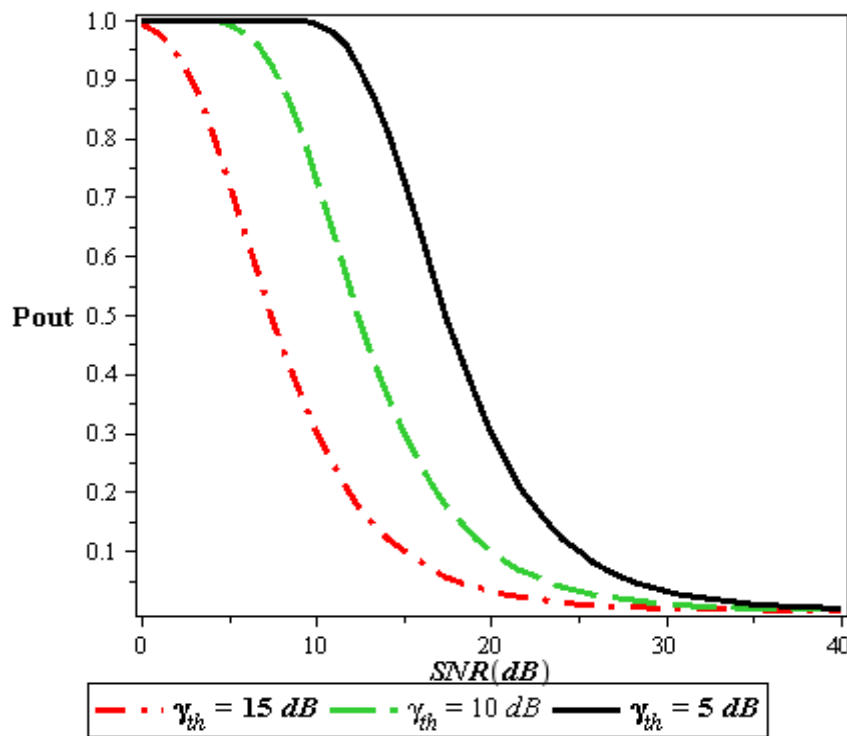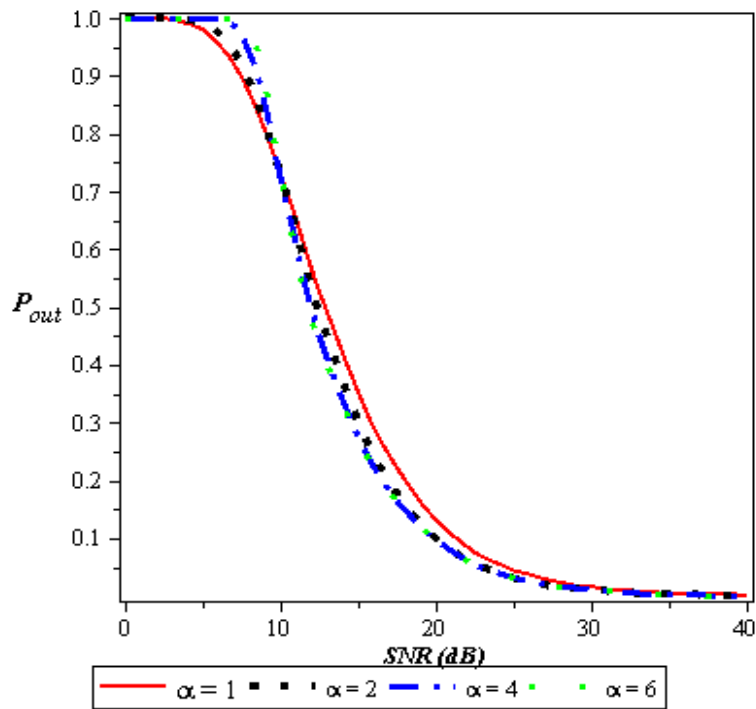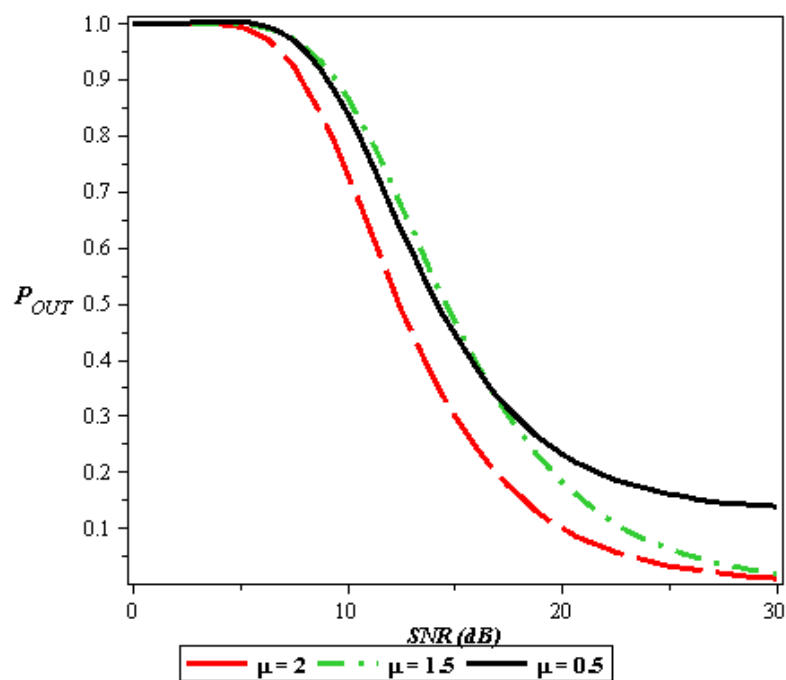

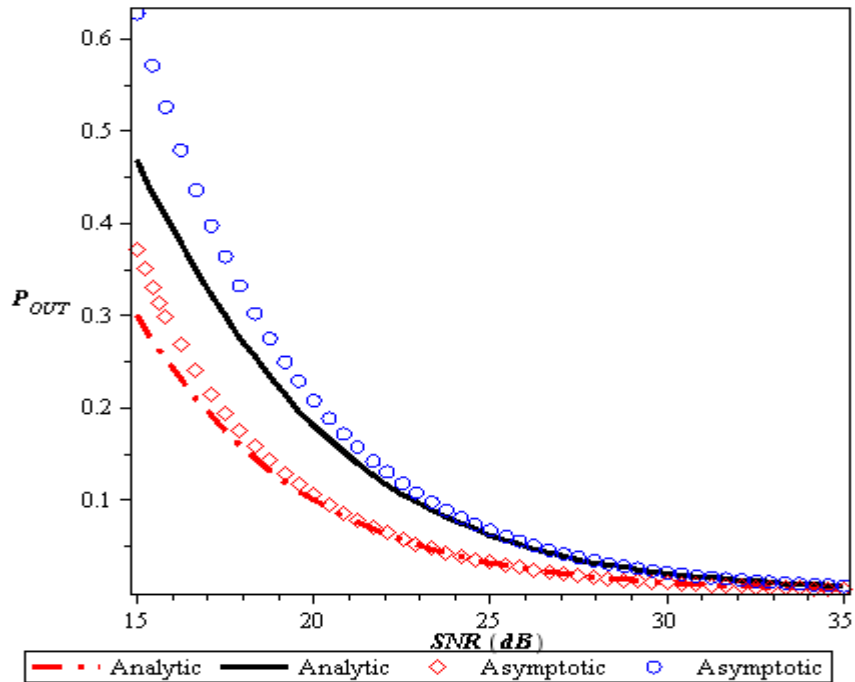**Figure 2. Outage Probability versus SNR for Various Values Threshold**

Figure 3. Outage Probability versus SNR for Various Values Channel Parameter (α)

Figure 4. Outage Probability versus SNR for Various Values Channel Parameter (μ)

Figure 2, shows Outage probability versus SNR plot for various values threshold SNR. For plot of Figure 2, we consider α = 2 and μ = 2. It is clear from the Figure that Outage probability improves with increase of SNR. Outage probability also improves with the

increase of threshold SNR. Figure 3 shows Outage probability versus SNR for various values channel parameter. It can be observed from the Figure,

Figure 5. Outage Probability versus SNR

that Outage probability improves with increase of SNR but it does not changes much with the channel of parameter α. Figure 4 shows Outage probability versus SNR for various values channel parameter (μ). It is clear from the Figure that improves with increase of SNR. Moreover, Outage probability also improves with the increase channel parameter (μ). Figure 5 shows asymptotic behavior outage probability of proposed analysis. It is clear from Figure that asymptotic results are well match with analytical results in high SNR regime which shows the correctness of proposed analysis.

6. Conclusions

In this research work, we present the mathematical modeling of a dual hop hybrid RF/FSO DF relaying system. More specifically, we provide closed loop expressions for outage probability for the proposed system. Moreover, we also show the effect of variation of various fading and channel parameters on the outage probability. In addition, we have also analyzed the asymptotic behavior proposed analysis which verifies the accuracy of proposed analysis. This technique may be useful for future wireless communication such as 5G wireless communication system.

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