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PERFORMANCE ANALYSIS OF HYBRID FSO/RF-FSO SYSTEM OVER α-μ SHADOWED AND FISHER-SNEDECOR Ƒ FADING MODEL USING LINK ADAPTION

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ABSTRACT

For 5G cellular backhaul networking, free-space optical (FSO) lines offer a low-cost, non-invasive alternative to fibre optic cables. We propose a millimetre-wavelength (MMW) RF-FSO link as a backup for FSO-based backhaul networks. By switching between the primary FSO link and the secondary RF-FSO link, an uninterrupted and reliable network connection can be achieved; when the primary link is disrupted by atmospheric turbulence, the secondary link maintains connectivity because the MMW RF link has complementary characteristics to atmospheric effects. We also create simple mathematical equations for several performance indicators like as outage probability, average bit error rate (BER) in order to analyse the improvement analytically. In terms of outage probability and BER, our findings show that FSO/RF-FSO topology outperforms a single FSO connection. An amplify and forward (AF) relay employing an average power scaling (APS) approach is used to create the dual-hop mixed RF-FSO connection. Irradiance is a measure of how bright something is.

Keywords: Free-Space Optics, Fisher Distribution, Backup RF-FSO Link, A-M Fading Channel, Link Switching, Outage Probability.

I. INTRODUCTION

While the concept of carrying RF signals FSO, requirement for 1 Gbps bandwidth per user is necessary to realise the promise of Internet-of-Things (IoT) in 5G networks, as the digital society of the next generation has become used to machine-to-machine (M2M) communication with high-speed Internet applications. In the Internet of Things, M2M communication would necessitate communication among a large number of linked devices. The task at hand is to build a backhaul infrastructure that can sustain a high node density while also carrying a massive volume of aggregated data. To increase capacity, network operators are shrinking cell sizes, but the backhaul network architecture is growing more complex and expensive with each additional base station. In 5G wireless networks, free-space optical communication (FSO) is predicted to be critical. Because of its simplicity of deployment, quick setup time, and low cost, FSO lines are a viable alternative to traditional fibre optic cables for backhaul connectivity.[1]

Using low-power infrared lasers in the terahertz spectrum, Free Space Optics (FSO) transmits invisible light beams from one 'telescope' to another. The light laser beam is centred on the receptors of highly sensitive photon detectors in free space optical (FSO) systems that emit light beams. FSO communication systems have a wide range of applications, from short-range (1 km) to long-range and space applications. It links end users to the spine with a broadband solution (high data speeds without cabling). Application with a short range.[2] In metropolitan areas where cable burial is problematic, offers last-mile access by linking many towers, buildings and other structures. It includes point-to-point (or point-to-point-to-point-to-point-to-point-to-point-multipoint links or broadband links.

For expanding coverage, enhancing communication reliability, and increasing throughput, the DUAL-HOP relaying technology has been a hot study issue. Band-width limitation, decreased data rate, and interference are major limiting issues for typical dual-hop relay-assisted radio frequency (RF)/RF systems. Due to the benefits of high data speeds, license-free spectrum, and immunity to interference, free space optical (FSO) communications have been used in the relaying scheme as a supplement to RF equivalents. [3]As a result, research into the performance of dual-hop mixed RF/FSO relaying systems has garnered a lot of interest. Some typical studies on these systems' performance measures (e.g., outage probability (OP), average bit error rate) (BER).

1.1. PRIOR WORK

While the connections in cellular mobile backhauls has been around for a while [4,] network topologies that combine RF and FSO links are relatively recent [5.] The suggested combinations are either serial, in which the cascaded link's intermediate node (relay node) is used for RF-optical conversion [6], or parallel, in which two network nodes are connected by a pair of RF and FSO connections to increase reliability [7]. In [8],[10], analytical equations for amount of fading, outage probability, bit/ symbol error rate, were developed for the serial RF-FSO combination. The parallel RF/FSO combination, on the other hand, is discussed in [11]–[13], where innovative coding techniques for switching between RF and FSO pathways are given. Different statistical models have been suggested for both parts of the connections as RF for channel characterization.

Again, distinct statistical models have been prescribed for both parts of the connections for channel characterization, as RF and FSO links encounter different atmospheric disturbances. Rayleigh [14], Rician [15], Nakagami-m [16], and extended distributions [17] have been suggested to explain multipath fading in the RF connection. The log-normal distribution has been used for a long time to characterize atmospheric turbulence-induced fading in FSO connections [18], despite the fact that the distribution is only suited for modelling light turbulence. According to recent experimental research, the k-u shadowed is the best choice for FSO channel modelling since it can mimic mild, moderate, and high atmospheric turbulence conditions [19], [20].

1.2. CONTRIBUTIONS

IN THIS PAPER:

- A hybrid FSO/RF-FSO transmission scheme is presented to increase the availability and reliability of next generation cellular backhaul networks. To the best of our knowledge, analysis of performance metrics for a backhaul system where the primary FSO backhaul link is augmented with a serial RF-FSO backup link, has not been reported in the open literature so far. The proposed system is different from a hybrid RF/RF-FSO implementation [21] where the mobile users communicate with the respective base station via a RF or a RF-FSO link.
- By modelling the RF fading and atmospheric turbulence induced FSO fading with Rayleigh and k-u Shadowed respectively, we derive analytical expressions for outage probability, average bit-error rate (BER).
- The derived mathematical expressions for different performance metrics are presented in terms of Fox H-functions that can be accurately and easily computed using MATLAB.
- Two different link switching strategies are examined - a single FSO threshold scheme which offers simplicity in transceiver design, and a dual FSO threshold scheme that prevents unnecessary switching between primary FSO link and backup mixed RF-FSO link.
- All the mathematical analyses are verified through MATLAB simulations.

1.3. ORGANIZATION

The rest of this paper is structured as follows.

In Section (2), describes the proposed system model followed by statistical channel modeling of the primary FSO link and the backup RF-FSO link. Section III describes the link switching operation in Algorithm under single FSO threshold scheme and presents analytical framework for calculation of outage probability and average BER. These sections contain the respective plots of numerical results as well. Finally, last Section concludes the paper with a brief summary and mentions possible directions to extend the current work. [21]

II. SYSTEM CONFIGURATION AND CHANNEL MODEL

The FSO link operates in combination with a mixed RF-FSO connection 2 in our proposed hybrid FSO/RF-FSO system, as shown in Fig. 1. In addition to the normal FSO transmitter, the source (S) has an RF transmitter. The relay (R) may receive an RF signal and then convert it to an FSO signal. There are two optical receivers at destination (D), one for receiving data via the S-D connection and the other for receiving data via the relay, i.e. via the S-R-D link.[22]

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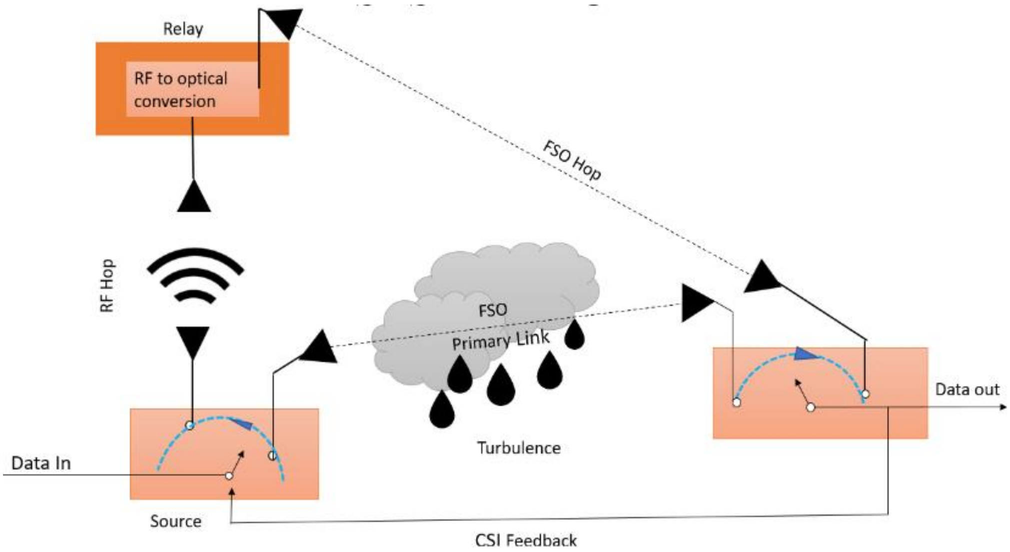

Fig 2.1: Dual hop mixed RF-FSO secondary link with source-to-relay RF link and relay-to-destination FSO link

A feedback path is used to send channel status information (CSI) over the primary FSO link from D to S. S switches from FSO to RF transmission and gives feedback to D, to switch over the receiver aligned with R if the primary FSO connection is hindered by air turbulence. S sends a pilot signal across the primary FSO link at regular intervals to measure the turbulence state. D validates the connection quality by giving feedback, and the primary FSO link is re-activated if it reaches the desired service level.[23]

We analyzed a dual-hop mixed RF/FSO system with k-u -shadowed and Fisher-Snedecor F fading channels. Using the switching technique [24], the relay node R transforms the RF signal to an optical signal, amplifies it, and sends it to the destination node D over the FSO connection.

2.1 MODELING THE PRIMARY FSO LINK

Atmospheric turbulence model to model the atmospheric turbulence, the Fisher-Snedecor F distribution is adopted with the PDF provided by

$$f_{Ia}(I_a) = \frac{a^a (b-1)^b I_a^{a-1}}{\beta(a,b)(aIa + b - 1)(aIa + b - 1)^{a+b}}$$

Where I_a is the real irradiance;

The probability density function (PDF) of the received instantaneous electrical β (.,.) is the beta function. a and b are the parameters including the turbulence refraction index structure parameter, the propagation path length, and the inner and the outer scale of turbulence, given by

$$a = \frac{1}{\exp\left(\sigma^2_{In\ Sy}\right) - 1} \quad , \; b = \frac{1}{\exp\left(\sigma^2_{In\ Sx}\right) - 1} + 2$$

Where $\sigma^2_{In\ Sy}$ and $\sigma^2_{In\ Sx}$ correspond to the small scale and large-scale log-irradiance variances.

The cumulative distribution function (CDF) of electrical SNR, $F_{\gamma 2}(\gamma 2)$, is found by using [24, eq. (8.4.23.1)] and integrating the PDF in

$$F_{\gamma 2}(\gamma 2) = 1 - \frac{\xi mod^2}{r\Gamma(a)\Gamma(b)} H^{3,1}_{3,3}\left[\frac{a\xi mod^2}{(b-1)(\xi mod^2+1)}\left(\frac{t}{\mu_r}\right)^{\frac{1}{r}} \middle| \begin{matrix} (1-b,1),(\xi mod^2+1,1),\left(1,\frac{1}{r}\right) \\ \left(0,\frac{1}{r}\right),(a,1),(\xi mod^2,1) \end{matrix}\right]$$

Where $\xi_{mod} = \frac{wLEQ}{2\sigma mod}$ and $\sigma_{mod} = \left(\frac{3\mu_x^2\sigma_x^4 + 3\mu_y^2\sigma_y^4 + \sigma_x^4 + \sigma_y^6}{2}\right)^{\frac{2}{3}}$,here μ_x and μ_y are the horizontal and elevatio displacement respectively. wLEQ represents the equivalent beam width. μ_r is the average electrical SNR w r=1 for HD and r=2 FOR DD. Value of parameters a=1.43 and b= 3.53. Here, H(.) is the Fox's H function.[

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2.2 Modelling the Backup RF-FSO Link

S connects with D via the backup S-R-D link when the primary link fails. We chose an average power scaling (APS) based fixed-gain decode-and-forward (DF) type relay since it is ideal for relay-based applications with a limited budget.

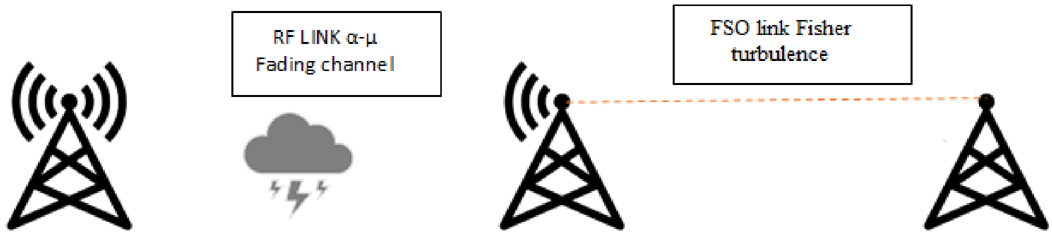

Fig 2.2: Dual hop backup RF-FSO link with S-R RF hop and R-D FSO hop

The S-R link can be represented by k-fading, but the R-D FSO link disturbances may be described by the Fisher-Snedecor F distribution in the presence of moderate to heavy air turbulence, as shown in Fig. 2. The relay's optical transmitter receives RF signals from the source antenna and converts them before sending an optical signal to the photo detector at the destination node lens.

The relay node R operates in half-duplex mode. When the variable-gain relaying scheme is considered, the end-to-end instantaneous SNR at the destination D can be expressed as

$$\gamma = \frac{\gamma_1 \gamma_2}{\gamma_1 + \gamma_2}$$

where γ_i is the instantaneous SNR of the i-th hop for i ∈(1,2)

The PDF of α-μ can be expressed as

$$F_x(x) = \frac{\propto \delta^{\delta} x x^{\alpha\delta-1}}{\Gamma(\delta)\boldsymbol{\Omega}_{\propto}^{\propto\delta}} G_{0,1}^{1,0}\left[\delta\left(\frac{x}{\boldsymbol{\Omega}_{\propto}}\right)^{\propto}\Bigg|_{0}^{-}\right]$$

The exact CDF expression in the terms of the bivariate Fox's H function. This completely coverages to the exact result in the high SNR regime, and is much more analytical tractable

$$F_Y(Y) = 1 - \frac{\propto \delta^{\delta} \varepsilon_{mod}^{2} \gamma^{\propto\delta}}{r\Gamma(a)\Gamma(b)\Gamma(\delta)\boldsymbol{\Omega}_{\propto}^{\propto\delta}}$$

$$*H_{0,1:3,2:2,0}^{0,0:1,3:0,2}\left[\frac{(b-1)(\varepsilon_{mod}^{2}+1)u_r^{1/r}}{a\varepsilon_{mod}^{2}\gamma^{1/r}}, \frac{\boldsymbol{\Omega}_{\propto}^{\propto\delta}}{\delta\gamma^{\alpha}}\left|\begin{matrix} -:(1-a,1),(1-\varepsilon_{mod}^{2},1)\left(1,\frac{1}{r}\right):(1,1),(1+\alpha\delta,\alpha) \\ (\alpha\delta,\frac{1}{r},\alpha:(b,1),(-\varepsilon_{mod}^{2},1):- \end{matrix}\right.\right|$$

III. SINGLE FSO THRESHOLD SCHEME

The signal level at D is checked at regular intervals to determine the quality of the high-speed primary FSO connection (PL). D gives input to S when the received signal level falls below a specific threshold, so that an adaptive algorithm may choose the best transmission channel for future data transfer. If SNR goes below a specific set FSO threshold, fso th, or if the quality of either of the RF or FSO links of a mixed RF-FSO transmission line also falls below a particular common threshold, mix th [11], S automatically changes over to the RF-FSO secondary link (SL).

3.1 LINK SWITCHING OPERATION

The transmission path variable X at time T is selected as per Algorithm. Link switching for single FSO threshold if primary fso ≥ ξfso threshold then the transmission path will be FSO i.e, X ← FSO. Else If ξrf greater than threshold and ξfso secondary link greater than threshold then X←RF-FSO else the Transmission suspended/ outage occure.

3.2 OUTAGE PROBABILITY ANALYSIS

An outage occurs when both primary S-D link and secondary S-R-D link are down as the SNRs do not meet the respective threshold levels. The outage probability is thus

$$F_{out}^{(1)} = F_{\gamma}^{fso(PL)}(\varepsilon_{th}^{fso})\, F_{\gamma 2}^{mix}(\varepsilon_{th}^{mix})$$

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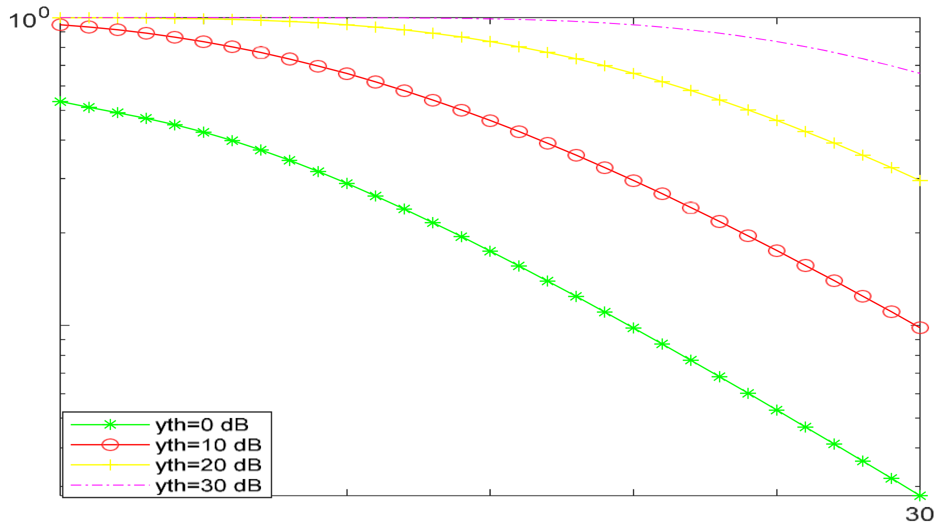
The numerical values obtained from the expressions developed for the outage probability are plotted and validated by MATLAB simulations . It may be seen that for an outage threshold of 5 dB, the outage probability is reduced by an order for an average electrical SNR of 30 dB, when we replace a single FSO link with the proposed hybrid FSO/RF-FSO setup[27] .

IV. RESULT AND DISCUSSON

MODERATE TURBULANCE



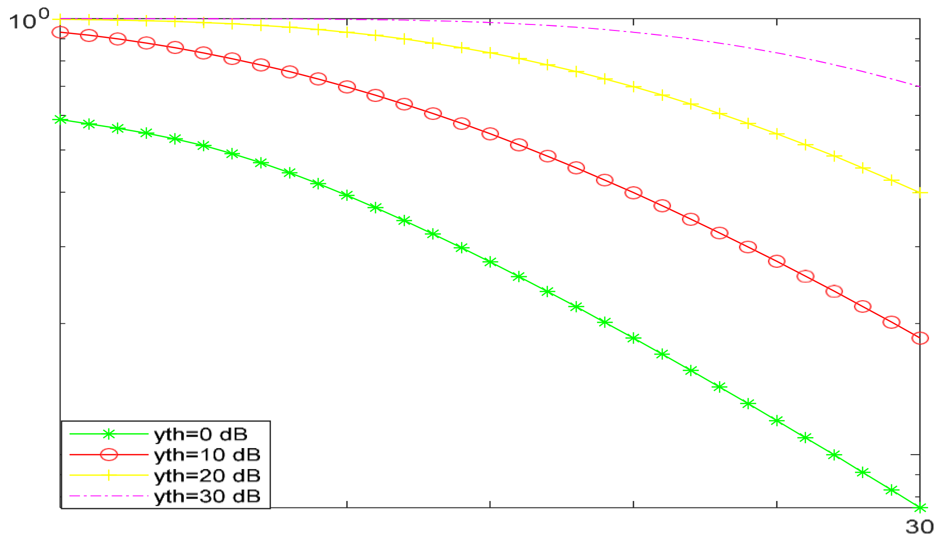
Average electrical SNR

Fig 4.1: Outage Probability over Mixture Gamma Fading

(Condition: N =1, α_1 , β_1 = 1, ζ_1 = 1)for dual-hop RF/FSO system under moderate turbulence conditions.

Fig 4.1 represents the Outage probability verses Average Electrical SNR over Mixture Gamma Fading (Condition: N = 1, α_1 = 1 , β_1 = 1, ζ_1 = 1)for Dual Hop RF/FSO system under moderate turbulence conditions. This shows that for a particular threshold as the average electrical SNR increases outage probability decreases. It is noticed that at average electrical SNR of 30 dB, the outage probability is 0.0279, 0.0982, 0.2856 & 0.6590 with threshold SNR γ_{th} of 0 dB, 10 dB, 20 dB & 30 dB respectively. Also, outage probability increases as threshold SNR γ_{th} increases for a particular SNR.[28] Further outage probability increased by 71% when SNR threshold increased from 0 dB to 10 dB, 66.7 % when SNR threshold increased from 10 dB to 20 dB and 55.1% SNR threshold increased from 20 dB to 30 dB

STRONG TURBULENCE



Average electrical SNR

Fig 4.2: Outage Probability over Mixture Gamma Fading

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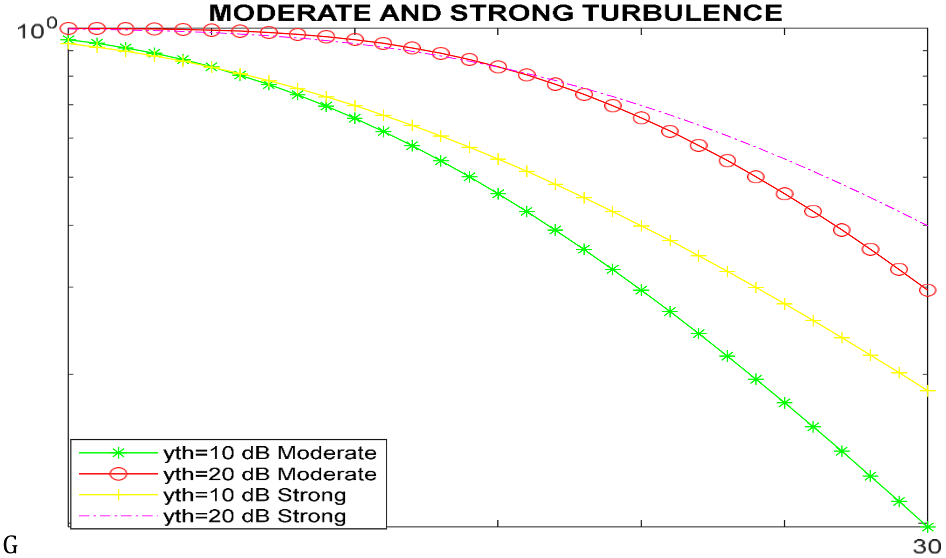
(Condition: N =1, $\alpha_1 = {}^{1}$, $\beta_1 = 1$, $\zeta_1 = {}^{1}$) for dual-hop RF/FSO system under strong turbulence conditions

Fig 4.2 represents the Outage probability verses Average Electrical SNR over Mixture

Gamma Fading (Condition: N = 1, $\alpha_1 = {}^{1}$, $\beta_1 = 1$, $\zeta_1 = {}^{1}$)for Dual Hop RF/FSO system under strong turbulence conditions. Similar to Fig.1 same trends are obtained for strong turbulence conditions. It is noticed that at average electrical SNR of 30 dB, the outage probability is 0.0759, 0.1851, 0.3988 & 0.6984 with threshold SNR γ_{th} of 0 dB, 10 dB, 20 dB & 30 dB respectively. Further outage probability increased by 59.2% when SNR threshold increased from 0 dB to 10 dB, 53.0 % when SNR threshold increased from 10 dB to 20 dB and 42.8% SNR threshold increased from 20 dB to 30 dB. This shows that outage probability is increased more when threshold SNR increased from 0 dB to 10 dB as compared to 10 dB to 20 dB. So we can concluded that as threshold SNR increases more, % change in increase in outage probability decreases [29]



Average electrical SNR

Fig 4.3: Comparison of Outage Probability over Mixture Gamma Fading

(Condition: N = 1, $\alpha_1 = {}^{1}$, $\beta_1 = 1$, $\zeta_1 = {}^{1}$)under dual-hop RF/FSO system.

$\bar{y}$ $\bar{y}$

Fig 4.3 represents the comparison of Outage probability verses Average Electrical SNR over Mixture Gamma Fading (Condition: N = 1, $\alpha_1 = {}^{1}$, $\beta_1 = 1$, $\zeta_1 = {}^{1}$)for Dual Hop RF/FSO system under strong and moderate turbulence conditions. It is noticed that at average electrical SNR of 30 dB, the outage probability is 0.0982 & 0.2956 under moderate turbulence condition when threshold SNR γ_{th} is 10 dB and 20 dB respectively. Similarly outage probability is 0.1851 & 0.3988 under strong turbulence condition when threshold SNR γ_{th} is 10 dB and 20 dB respectively. This shows that as the fading severity increased from moderate to strong outage performance decreases. Further outage performance decreased by 46.9% & 25.8% when fading severity increased from moderate to strong for SNR threshold of 10 dB & 20 dB respective.[30]

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Outage Probability for Nakagami-m and Double GG distribution

MODERATE TURBULENCE

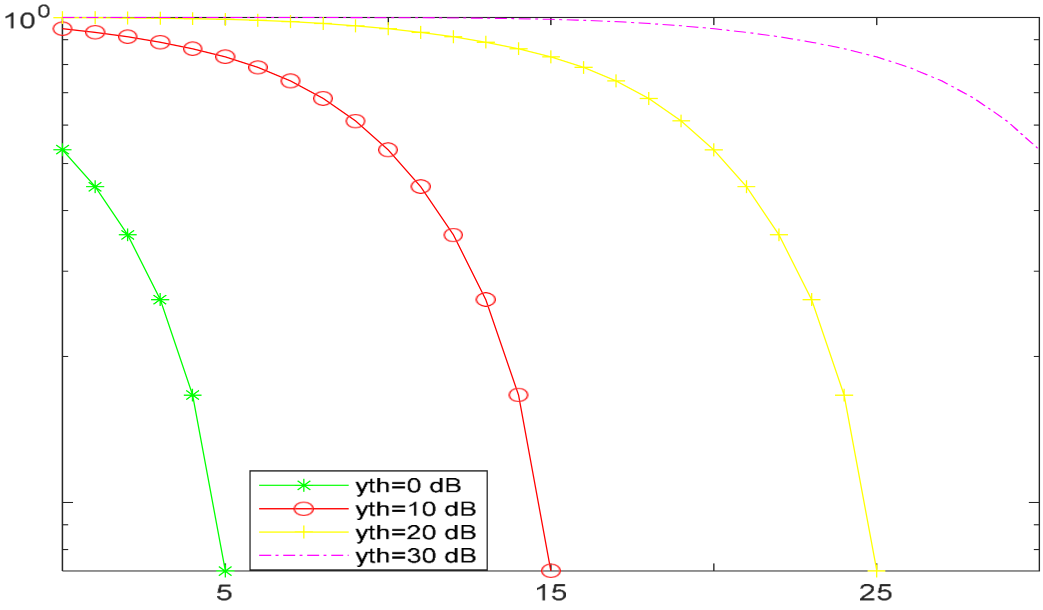


Fig 4.4 Outage Probability over Mixture Gamma Fading (Condition:N = 1,mm T(m)y¯m,β_1= m , ζ_1= m) for dual-hop RF/FSO system under moderate turbulence conditions

Fig 4.4 represents the Outage probability verses Average Electrical SNR over Mixture Gamma Fading (Condition: N = 1, $\alpha_1$mm T(m)y¯m, β_1= m , ζ_1= m) for Dual Hop

y¯

RF/FSO system under moderate turbulence conditions. This shows that for a particular threshold as the average electrical SNR increases outage probability decreases. Also, as threshold SNR γ_{th} increases outage is achieved for higher SNR. Further outage achieved till SNR of 5 dB for threshold SNR γ_{th} of 0 dB, 15 dB for threshold SNR γ_{th} of 10 dB, 25 dB for threshold SNR γ_{th} of 20 dB and 30 dB for threshold SNR γ_{th} of 30 dB respectively.[31]It is noticed that at average electrical SNR of 5 dB, the outage probability is 0.0722, 0.8292, 0.999 & 0.999 with threshold SNR γ_{th} of 0 dB, 10 dB,20 dB & 30 dB respectively.

STRONG TURBULENCE

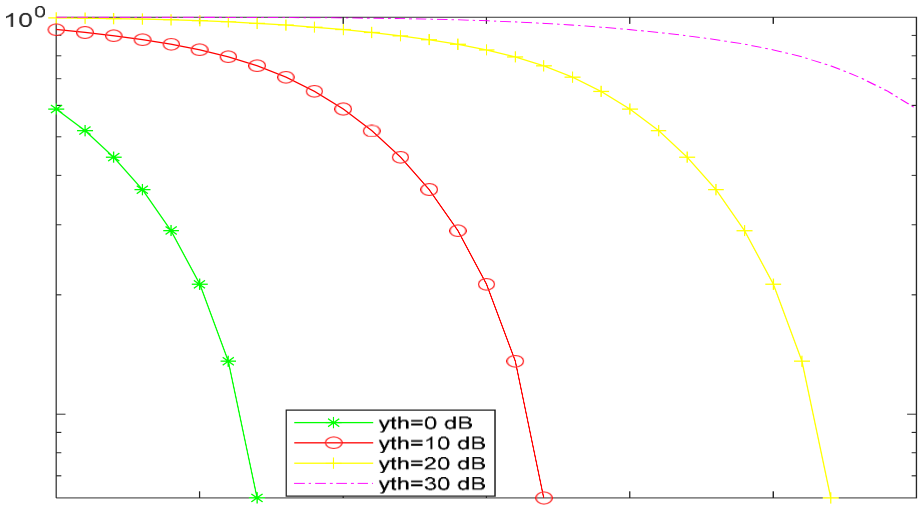
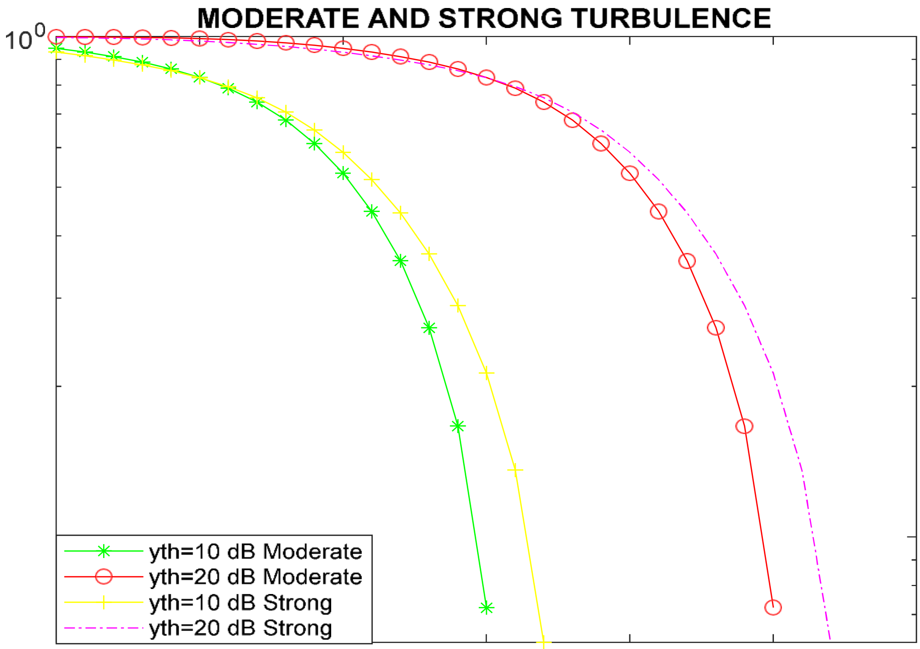


Fig 4.5 Outage Probability over Mixture Gamma Fading (Condition: N = 1, α_1 = mm T(m)y¯m, β_1= m , ζ_1= m) for dual-hop RF/FSO system under strong turbulence conditions

Fig 4.5 represents the Outage probability verses Average Electrical SNR over Mixture.

Gamma Fading (Condition: N = 1, $\alpha_1$mm T(m)y¯m, β_1= m , ζ_1= m) for Dual Hop

RF/FSO system under strong turbulence conditions. Similar to Fig.4 same trends are obtained for strong turbulence conditions Also, as threshold SNR γ_{th} increases outage is achieved for higher SNR. Further outage achieved till SNR of 7 dB for threshold SNR γ_{th} of 0 dB, 17 dB for threshold SNR γ_{th} of 10 dB, 27 dB for threshold SNR γ_{th} of 20 dB and 30 dB for threshold SNR γ_{th} of 30 dB respectively. It is noticed that at average electrical SNR of 7 dB, the outage probability is 0.0615, 0.7549, 0.9656 & 0.999 with threshold SNR γ_{th} of 0 dB, 10 dB, 20 dB & 30 dB respectively



Average electrical SNR

Fig 4.6 represents the comparison of Outage Probability over Mixture Gamma Fading (Condition :N = 1, α_1=mm T(m)y¯m, β_1= m , ζ_1= m)under dual-hop RF/FSO system

Fig 3.6 represents the comparison of Outage probability verses Average Electrical SNR over Mixture Gamma Fading (Condition: N = 1, α_1=mm T(m)y¯m, β_1= m , ζ_1= m)for

Dual Hop RF/FSO system under strong and moderate turbulence conditions. It is noticed that at average electrical SNR of 10 dB and threshold SNR γ_{th} of 10 dB, the outage probability is 0.5336 & 0.5875 under moderate and strong turbulence condition respectively. This shows that as the fading severity increased from moderate to strong outage performance decreases. Further outage performance decreased by 9.1% when fading severity increased from moderate to strong for SNR threshold of 10 dB

V. CONCLUSION

In this work we studied the performance of hybrid RF/FSO system in terms of Outage Probability. RF channel is modelled using α-μ distribution and FSO channel is modelled using fisher-Snedecor F distribution. The analytical closed form expressions for the cumulative CDF and Outage probability have derived for heterodyne detection techniques and Direct detection technique. k-μ distribution is used as special cases of α-μ distribution. It is observed that for a particular threshold as the average electrical SNR increases outage probability decreases. Also, outage probability increases as threshold SNR γ_{th} increases for a particular SNR. However, as threshold SNR increases more, % change in increase in outage probability decreases. Further as the fading severity increased from moderate to strong outage performance decreases.

Simulation of other Channel models as special cases α-μ distribution can be future scope of this work.

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