Performance Analysis of UAV-Aided Wireless Communication Systems with Ubiquitous Coverage

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***Abstract*—The unmanned aerial vehicles (UAVs) can serve for key applications in wireless communications. Cellular systems can be assisted by UAVs to provide ubiquitous coverage and additional capacity to overloaded base-stations. In this paper, we present the performance analysis of UAV assisted wireless communication system for ubiquitous coverage. In the considered system, the source and the destination terminals have single transmit and receive antennas, on the other hand the UAV node has multiple transmit and receive antennas. The closed form expression of the bit error rate (BER) performance for the considered system over generalized two-wave with diffused power (TWDP) fading is derived in particular. The performance analysis is done considering direct line of sight (LOS) and multi-path components between source-UAV-destination links. The results are analyzed for Rician and Rayleigh fading channel as a specific case of TWDP distribution. Moreover, in order to get the better insights of the system, we also perform the asymptotic analysis for the considered system. Simulation results are presented for different scenarios and it is observed that simulation results shows excellent agreement with the analytical results.**

***Index Terms*—Unmanned Aerial Vehicle, DF, TWDP, BPSK, MRC.**

I. INTRODUCTION

The use of flying platforms like unmanned aerial vehicles (UAVs) is expeditiously increasing for wide range of applications in wireless networking. In order to support the increasing demand for uninterrupted connectivity in the wireless communications system, UAVs can be one potential alternative as a flying relay in scenarios like Long-haul communication (symmetric hop), urban cellular communication (asymmetric hop) etc. UAVs can be used as flying base stations to provide a cost-effective on-demand communication link to support existing wireless networks. Owing to its inherent advantage of mobility and adjustable altitude, the UAVs can aid the existing cellular networks in terms of the additional capacity and ubiquitous coverage in difficult and remote terrains. Another potential use-case of UAVs lies with Internet of Things (IoT) scenarios by assisting long range improved connectivity of samll transmit power devices. Some of the widely accepted use-cases of UAVs include UAV-aided ubiquitous coverage, data collection and UAV-aided relaying and UAV-aided information dissemination.

In [1], the role of interference in the air to ground (ATG) communications is appropriately considered in the scenario of co-existing terrestrial base stations and UAVs assisted base stations. The authors highlight that the dominance of LoS links makes inter-cell interference a critical issue for cellular systems with hybrid terrestrial and aerial UEs. However, there exists several literatures [2], [3] which explores the feasibility of providing cellular connectivity for UAVs. There can be multiple types of interference in the ATG system. The architecture of drone cells results in significant interference in ATG communications which requires a appropriately designed interference management system. Further, user equipments may suffer from the the interference form the other UAVs. Other emerging technologies like beamforming and MIMO can be further utilized to enhance the performance. A tradeoff between the coverage and interference can be achieved by dynamically adjusting the transmission power and altitude of UAVs. Further OFDM can be used to avoid interference among users in each cell as mentioned in [2].

The ground to air channel for the piloted platforms are well explored, however the research on the systematic measurement and channel modelling for ground-UAV link is still ongoing [4]. The modeling of UAV-ground link is more difficult task due to the complicated environments. Although, these links are expected to be line-of-sight (LoS), but due to difficult terrains, high rise building there are chances of shadowing, leading to unavailability of LoS. Also, the low altitude ground-UAV channels may have numerous multipath components arising from scattering, diffraction etc. It is observed form the literature that the two-ray model is one of the suitable channel model for the UAVs operating over the open areas like sea, deserts, due to easy availability of LoS and surface reflection.Some significant work has been done by the researchers in the past based on ergodic capacity of UAV system based on amplify-and-forward (AF) scheme for Rayleigh channel model [5]. However, for the environment with LoS component and random scattered components, the Rician fading model is the preferred one. Also, various studies have been done for specific channel modelling of air-ground channels of UAV's based on rician model for suburban/hilly environment [6].

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Massive MIMO, which is one of the potential technology component of emerging 5G cellular networks can help in achieving the ever-increasing demand of data rate. Authors in [7] specifically discuss about application of Massive MIMO in assisted communication systems to offer support for fast-moving drones, significant range extensions and to spatially multiplex the entire swarms of drones communicating simultaneously. The two-wave with diffused power (TWDP) distribution proposed in [8], has attracted much attention as it perfectly fits into more realistic frequency selective fading data collected from wireless sensor networks. The TWDP distribution is a generalized one, which models many practical wireless communication systems. The TWDP distribution takes into consideration some of the well known fading distribution as its special cases, e.g. Rayleigh distribution (for K=0) and Rician distribution (for Δ=0).

In this paper, we consider a scenario in which a UAV is used as a relay [9], [10] at low altitude platforms enabling a direct link between the base station$-$UAV and UAV$-$destination. Due to mobile attribute, UAV can avoid obstacles by adjusting its altitude and can establish LOS communication link. UAV receives a signal sent by the source and forwards it to the destination through both direct LOS link and the multi-path components. Hence, we consider a Rician wireless fading scenario as a special case of TWDP fading with symmetric as well as asymmetric channel conditions. We consider BPSK signalling for different Rician factor K, denoting the power ratio between the LOS component and the spectral components. To the best of the authors knowledge, the performance of DF relaying scheme with multiple antennas at the UAV over TWDP fading has not been analyzed yet. Following are the novel contribution of the work: 1) We present the novel closed-form expressions of average BER for a decode-and-forward (DF) based system having multiple receive antennas at the UAV relay node and single receive antenna at the destination node over TWDP fading. 2) An asymptotic approximation is further derived for the end-to-end proposed system. 3) Further, to validate the system analysis, Monte-Carlo simulations are presented for each case.

The rest of the paper is organized as follows. System model and TWDP fading channel is described in section II. The performance analysis is presented in section III. In section IV, numerical results and discussions are given and the paper is concluded in section V.

II. SYSTEM AND CHANNEL MODEL

We consider a UAV based cooperative relayed system [11] with a source node with single transmit antenna, a UAV relay node with multiple transmit and receive antennas and a destination node with single receive antenna, as shown in Fig. 1. All the source-UAV and UAV-destination links are considered to Rician faded. In the considered system, it is assumed that there is no direct link between the source and the destination node due to difficult terrain/remote conditions. Hence, UAV serves to establish the communication links between the two non-LoS distant nodes. Since, we are considering DF scheme [12], hence, all the signals received by UAV are decoded and forwarded to the destination through multiple antennas at the UAV. Further, to combine signals through multiple antennas we make use of maximal ratio combining (MRC) technique. All the links are assumed to be slow faded with TWDP statistics. For transmitted signal $x(t)$ the received signal is given as

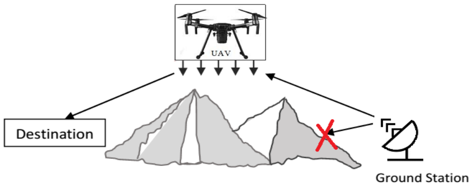

Fig. 1. Considered system model.

$$y(t) = re^{j\phi}x(t) + n(t), \tag{1}$$

where $n(t)$ is the Additive White Gaussian Noise (AWGN), ϕ is the random variable (RV) for instantaneous phase of the signal, r $\in$ R is TWDP distributed fading envelope. The probability density function (PDF) of random variable R is given as in [8] as

$$f_R(r) = \frac{r}{\sigma^2} \cdot e^{(-K-\frac{r^2}{2\sigma^2})} \sum_{i=1}^{\hat{l}} c_i \cdot D\left(\frac{r}{\sigma}; K, \alpha_i\right), \tag{2}$$

where $2\sigma^2$ is average power of diffuse waves, rice factor K stands for total specular power/total diffuse power, $\alpha_i = \Delta.\cos\left(\frac{\pi(i-1)}{2L-1}\right)$ where Δ is the relative strength of two specular components, so $\alpha_i = 0$ and c_i is coefficient whose value is given in [8] and $D\left(\frac{r}{\sigma}; K, \alpha_i\right) = \frac{1}{2}e^{\alpha_i K}\left(I_0\left(x\sqrt{2K(1-\alpha_i)}\right)+I_0\left(x\sqrt{2K(1+\alpha_i)}\right)\right)$, where, $I_0(.)$ is the zeroth-order Bessel function. If $K = 0$ then this TWDP distribution results in Rayleigh faded channel and if $\Delta = 0$ then it approximates to Rician faded channel. The instantaneous signal-to-noise ratio (SNR) is given by $\gamma = R^2\left(\frac{E_s}{N_0}\right)$, and the PDF for the instantaneous SNR is given as

$$f_\gamma(\gamma) = \frac{\hat{K}}{2\bar{\gamma}} \sum_{i=1}^{\hat{l}} \sum_{j=0}^{i} c_i . e^{\left(-K-\frac{\hat{K}\gamma}{\bar{\gamma}}\right)} I_0\left(2\sqrt{\frac{\hat{K}K\gamma}{\bar{\gamma}}}\right), \tag{3}$$

where $\hat{K} = K + 1$, $\bar{\gamma} = 2\sigma^2\hat{K}\left(\frac{E_s}{N_0}\right)$ and $\hat{l}$ is the order of TWDP fading. The generalized expression of moment

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generating function for a received random variable through generalized fading is given as in [13] as

$$M_{\gamma}(s) = \frac{\hat{K}}{2}\sum_{i=1}^{\hat{l}}\sum_{j=0}^{1}\frac{c_i}{(\hat{K}+s\bar{\gamma})}\exp\left(\frac{-s\bar{\gamma}P_{2i-j}}{\hat{K}+s\bar{\gamma}}\right), \quad (4)$$

For a dual-hop system with DF relaying [14], [15], the equivalent end-to-end instantaneous SNR is obtained as $\gamma = \min(\gamma_0, \gamma_1)$, where γ_0 and γ_1 are instantaneous SNR for ground station-UAV and UAV-destination links, respectively. Further, the equivalent end-to-end SNR can be evaluated as

$$F_{\gamma}(\gamma) = F_{\gamma_0}(\gamma) + F_{\gamma_1}(\gamma) - F_{\gamma_0}(\gamma)F_{\gamma_1}(\gamma), \quad (5)$$

Correspondingly, the probability density function (PDF) for the equivalent end-to-end SNR is given as

$$f_{\gamma}(\gamma) = f_{\gamma_0}(\gamma) + f_{\gamma_1}(\gamma) - F_{\gamma_0}(\gamma)f_{\gamma_1}(\gamma) - F_{\gamma_1}(\gamma)f_{\gamma_0}(\gamma). \quad (6)$$

Further, if all the links are considered to be i.i.d. then $f_{\gamma_0} = f_{\gamma_1}$ and (6) can be reduced as

$$f_{\gamma}(\gamma) = 2f_{\gamma_0}(\gamma) - (f_{\gamma_0}(\gamma))^2. \quad (7)$$

III. PERFORMANCE ANALYSIS

In this section, we present the error performance of the considered cooperative system model [16]. Firstly, we derive the closed-form expression for error probability of a single hop in multiple link scenario over TWDP fading and BPSK signalling. We employ the MRC technique at the receiving node which linearly combines the received signal to maximize the SNR of the received signal. Further, utilizing the derived closed form expression of error probability over multiple links, we derive the novel closed form expression for average bit error rate (BER) of the end-to-end UAV assisted relaying system over TWDP fading. We also perform the asymptotic analysis for the high SNR scenario to get the better insights of the system.

A. Average BER of MRC Receiver over TWDP Fading

The error probability for BPSK signalling over TWDP faded multiple link scenario can be obtained by averaging the conditional BER for AWGN channel over the PDF of the output SNR [17]. The mathematical expression of average BER is

$$\mathcal{P}_s(e) = \int_0^{\infty} Q\left(\sqrt{\gamma}\right)\cdot f_{\gamma}(\gamma)d\gamma, \quad (8)$$

Further, utilizing the alternate expansion of Q-function, i.e. $Q(x) = \frac{1}{\pi}\int_0^{\pi/2} e^{\left(-\frac{x^2}{2\sin^2\theta}\right)}d\theta$ and (4) in (8), we get

$$\mathcal{P}_s(e) = \frac{1}{\pi}\int_0^{\pi/2}\mathbb{M}_{\gamma,K}(s)d\theta, \quad (9)$$

where $s = \left(\frac{-x^2}{2\sin^2\theta}\right)$. Substituting value of $\mathbb{M}_{\gamma,K}(s)$ from (4) in (9), we get

$$\mathcal{P}_s(e) = \frac{1}{\pi}\int_0^{\pi/2}\left(\frac{\hat{K}}{\hat{K}+s\bar{\gamma}}\right)\cdot\exp\left(\frac{-Ks\bar{\gamma}}{\hat{K}+s\bar{\gamma}}\right)d\theta, \quad (10)$$

Further, extending (9) for L Rician independent and identically distributed (i.i.d.) faded links with symmetric Rice factor (K), the corresponding average BER over TWDP faded channel is given as in [17] as

$$\mathcal{P}_s(e) = \frac{1}{\pi}\int_0^{\pi/2}(\mathbb{M}_{\gamma,K}(s))^L d\theta, \quad (11)$$

Using (4) and (11), we can derive the expression of average BER over TWDP faded channel over L i.i.d. links as

$$\begin{aligned}\mathcal{P}_s(e) &= \frac{1}{\pi}\int_0^{\frac{\pi}{2}}\left(\mathbb{M}_{\gamma,K}(s)\right)^L d\theta \\ &= \frac{1}{4}\cdot\frac{2^{L-1}\hat{K}^L x\sqrt{\bar{\gamma}\delta^2}}{\left(2\hat{K}+x^2\bar{\gamma}\delta^2\right)^{\frac{3}{2}+L-1}}\sum_{i=1}^{\hat{l}}\sum_{j=0}^{i}c_i e^{(-L\cdot P_{2i-j})} \\ &\quad\times\phi\left(\frac{3}{2},1,2,\frac{2\hat{K}}{2\hat{K}+x^2\bar{\gamma}\delta^2},\frac{2L\hat{K}P_{2i-j}}{2\hat{K}+x^2\bar{\gamma}\delta^2}\right), \quad (12)\end{aligned}$$

where, $x = 1$ for BPSK signalling, δ^2 represents variance of TWDP faded link, and ϕ is a hypergeometric function of two variables and shown in [18] as

$$\phi\left(a,b,c,x_1,x_2\right) = \frac{\Gamma(c)}{\Gamma(a)\cdot\Gamma(c-a)}\int_0^1 u^{a+L-2}\cdot e^{-Lux_2}\cdot\frac{(1-u)^{c-a-1}}{(1-ux_1)^b}du,$$

B. Average BER of End-to-End system

In this subsection we analyze the error performance of the end-to-end UAV assisted cooperative system by utilizing the derived error performance statistics in the previous subsection. Using (7) and (12) the closed form expression for the considered end-to-end system if the system models for both $S \rightarrow R$ and $R \rightarrow D$ links are considered to be identical can be given as:

$$\mathcal{P}_s(e) = \frac{1}{\pi}\left[\int_0^{\frac{\pi}{2}}\left(2\left(\mathbb{M}_{\gamma,K}(s)\right)^L - \left(\mathbb{M}_{\gamma,K}(s)\right)^{2L}\right)d\theta\right], \quad (13)$$

If both $S \rightarrow R$ and $R \rightarrow D$ links are non-identical i.e. the Rice factor K for both the links are not similar then the closed from expression can be given as:

$$\begin{aligned}\mathcal{P}_s(e) = \frac{1}{\pi}\Bigg[\int_0^{\frac{\pi}{2}}\Big(&\left(\mathbb{M}_{\gamma,K_{sr}}(s)\right)^L + \left(\mathbb{M}_{\gamma,K_{rd}}(s)\right)^L \\ &- \left(\mathbb{M}_{\gamma,K_{sr}}(s)\right)^L \times \left(\mathbb{M}_{\gamma,K_{rd}}(s)\right)^L\Big)d\theta\Bigg], \quad (14)\end{aligned}$$

Using the derived expression in (12), the above equation (14) can be simplified to get closed form expression for the end-to-end system model with UAV assisted relay node as shown

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$$
\begin{aligned}
\mathcal{P}(e) = \frac{1}{4}\sum_{i=1}^{\hat{l}}\sum_{j=0}^{i} c_i e^{-L\cdot P_{2i-j}} \Bigg[& \frac{2^{L-1}\hat{K}_{sr}^{L} x\sqrt{\bar{\gamma}\delta^2}}{(2\hat{K}_{sr}+x^2\bar{\gamma}\delta^2)^{\frac{3}{2}+L-1}} \phi\left(\frac{3}{2},1,2,\frac{2\hat{K}_{sr}}{2\hat{K}_{sr}+x^2\bar{\gamma}\delta^2},\frac{2L\hat{K}_{sr}(P_{2i-j})}{2\hat{K}_{sr}+x^2\bar{\gamma}\delta^2}\right) \\
& + \frac{2^{L-1}\hat{K}_{rd}^{L} x\sqrt{\bar{\gamma}\delta^2}}{(2\hat{K}_{rd}+x^2\bar{\gamma}\delta^2)^{\frac{3}{2}+L-1}} \phi\left(\frac{3}{2},1,2,\frac{2\hat{K}_{rd}}{2\hat{K}_{rd}+x^2\bar{\gamma}\delta^2},\frac{2L\hat{K}_{rd}(P_{2i-j})}{2\hat{K}_{rd}+x^2\bar{\gamma}\delta^2}\right)\Bigg] - \left(\frac{1}{4}\sum_{i=1}^{\hat{l}}\sum_{j=0}^{i} c_i e^{-LP_{2i-j}}\right)^{2} \Bigg[\frac{2^{L-1}\hat{K}_{sr}^{L} x\sqrt{\bar{\gamma}\delta^2}}{(2\hat{K}_{sr}+x^2\bar{\gamma}\delta^2)^{\frac{3}{2}+L-1}} \\
& \phi\left(\frac{3}{2},1,2,\frac{2\hat{K}_{sr}}{2\hat{K}_{sr}+x^2\bar{\gamma}\delta^2},\frac{2L\hat{K}_{sr}(P_{2i-j})}{2\hat{K}_{sr}+x^2\bar{\gamma}\delta^2}\right) \times \frac{2^{L-1}\hat{K}_{rd}^{L} x\sqrt{\bar{\gamma}\delta^2}}{(2\hat{K}_{rd}+x^2\bar{\gamma}\delta^2)^{\frac{3}{2}+L-1}} \phi\left(\frac{3}{2},1,2,\frac{2\hat{K}_{rd}}{2\hat{K}_{rd}+x^2\bar{\gamma}\delta^2},\frac{2L\hat{K}_{rd}(P_{2i-j})}{2\hat{K}_{rd}+x^2\bar{\gamma}\delta^2}\right)\Bigg].
\end{aligned}
\tag{19}
$$

in (19). This equation can further be simplified for symmetric case by putting $K_{sr} = K_{rd} = K$.

C. Asymptotic Analysis

In this subsection, we analyze the considered system for high SNR scenario and perform the asymptotic analysis. At high SNR, i.e. $\bar{\gamma} >> k$, following assumptions hold

$$\exp\left(\frac{K\hat{K}}{K+1+s\bar{\gamma}}\right) \approx \exp\left(\frac{K}{1+\frac{s\bar{\gamma}}{\hat{K}}}\right) \approx 1 \tag{15}$$

$$\hat{K}sin^2\theta + x^2\bar{\gamma} \simeq x^2\bar{\gamma} \tag{16}$$

Further using the valid assumptions from (15) and (16) in (12) and performing some rigorous mathematics, we get

$$\mathcal{P}_s^{asy}(e) \approx \frac{1}{2}\left(\frac{2\hat{K}}{x^2\bar{\gamma}}\cdot e^{-K}\right)^{L} \frac{(2L-1)!!}{(2L)!!} \tag{17}$$

Further, utilizing (13) and (17), we obtain the asymptotic expression of the average BER of the considered end-to-end system as shown in (18).

$$
\begin{aligned}
\mathcal{P}^{asy}(e) \approx & \frac{(2L-1)!!}{2\,(2L)!!}\left[\left(\frac{2\hat{K}_{sr}e^{-K_{sr}}}{x^2\bar{\gamma}\delta^2}\right)^{L} + \left(\frac{2\hat{K}_{rd}e^{-K_{rd}}}{x^2\bar{\gamma}\delta^2}\right)^{L}\right] \\
& - \frac{1}{2}\left(\frac{4\hat{K}_{sr}\hat{K}_{rd}}{x^4\bar{\gamma}^2\delta^4}e^{-(K_{sr}+K_{rd})}\right)^{L}\left(\frac{(2L-1)!!}{(2L)!!}\right)^{2},
\end{aligned}
\tag{18}
$$

D. Outage Probability

In this subsection, we derive the closed-form expression of the outage probability for the considered system utilizing the MGF based approach. The generalized expression of the MGF of the TWDP fading link is given as in (4). Further for L i.i.d. links the overall MGF is given as

$$\overline{M}_{\gamma}(s) = \int \left(M_{\gamma_i}(s)\right)^{L} d\gamma \tag{22}$$

Where, $\overline{M}_{\gamma}(s) = M_{\gamma_1}(s)\cdot M_{\gamma_2}(s)\cdots M_{\gamma_L}(s) = \prod_{i=1}^{L} M_{\gamma_i}(s)$ Now since the considered system consist of UAV as a relay node, the source to relay and relay to destination link can be considered as Rician faded link as a special case of TWDP $(\Delta = 0)$. So, for Rician fading as a special case of TWDP $\Delta = 0$, and $P_{2i-j} = K, c_i = 1$, further using (4) and (22),the generalize expression of MGF for L i.i.d. TWDP faded links is given by

$$\overline{M}_{\gamma}(s) = \left(\frac{\hat{K}}{2}\sum_{i=1}^{L}\sum_{j=0}^{1}\frac{c_i}{(\hat{K}+s\bar{\gamma})}\exp\left(\frac{-s\bar{\gamma}k}{\hat{K}+s\bar{\gamma}}\right)\right)^{L} \tag{23}$$

Since $S-R$ and $R-D$ links both consisting of L independent and identically distributed links, thus we can have a realistic assumption that $(\mathcal{P}_{out}^{SR}) = (\mathcal{P}_{out}^{RD}) = (\mathcal{P}_{out})$. Therefore the end-to-end outage probability for the considered system can be obtained as

$$
\begin{aligned}
\mathcal{P}_{outage} &= (\mathcal{P}_{out} + \mathcal{P}_{out}) - (\mathcal{P}_{out}\cdot\mathcal{P}_{out}) \\
&= 2\mathcal{P}_{out} - \mathcal{P}_{out}^2,
\end{aligned}
\tag{24}
$$

where, $(\mathcal{P}_{out})$ can be obtained by substituting (23) in (25) [19]. .

IV. SIMULATION RESULTS

In this section, we present the analytical results for the considered UAV assisted end-to-end system and further validate our analysis through Monte-Carlo simulations. The results are presented for varying number of antennas at the UAV relaying node, i.e. for $L = [1, 2, 4]$. All the links $S \to R$ and $R \to D$ are considered to be TWDP faded with $\Delta = 0$ (leading to Rician fading) with symmetrical Rice-factor K.

The simulation results also takes into account varying channel gains for $S \to R \to D$ links. For simulation we have considered two scenarios: $a)$ Long distance communication the source and destination are far away from each other thus, UAV are usually located much closer to the destination than source and hence, the Rice factor K is usually larger for $R \to D$ than $S \to R$ links. $b)$ short distance communication like device to device UAVs can be located symmetrically between source and destination. Hence, there is a need to consider both asymmetric and symmetric channel conditions for better insights of the communication model. The Fig. 2 illustrates the average BER performance of the considered system with symmetric Rice factor K = $[0, 1, 3]$ with single antenna at the UAV relay node for δ_{sr} = δ_{rd} = 1. For K = 0 model behaves as Rayleigh faded channel, while for K = $[1, 3]$ model behaves as Rician faded channel. Further, observed that the system performance improves with increment in Rician factor K which validates the fact that as the power of the LoS component increases, the performance of the system

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$$P_{out} = P_{\gamma_t}\left(\gamma_{th}\right) = \frac{2^{-}K\, e^{A/2}}{\gamma_{th}} \sum_{k=0}^{K} \binom{K}{k} \sum_{n=0}^{N+k} \frac{(-1)^n}{\alpha_n} \times Re\left\{ \frac{M_\gamma\left(-\frac{A+2\pi jn}{2\gamma_{th}}\right)}{\frac{A+2\pi jn}{2\gamma_{th}}} \right\} + E(A,K,N)$$

$$|E(A,K,N)| \leq \frac{e^{-A}}{1+e^{-A}} + \left| \frac{2^{-K} e^{A/2}}{\gamma_{th}} \sum_{k=0}^{K} (-1)^{N+k+1} \binom{K}{k} \times Re\left\{ \frac{M_\gamma\left(-\frac{A+2\pi j(N+k+1)}{2\gamma_{th}}\right)}{\frac{A+2\pi j(N+k+1)}{2\gamma_{th}}} \right\} \right| \tag{25}$$

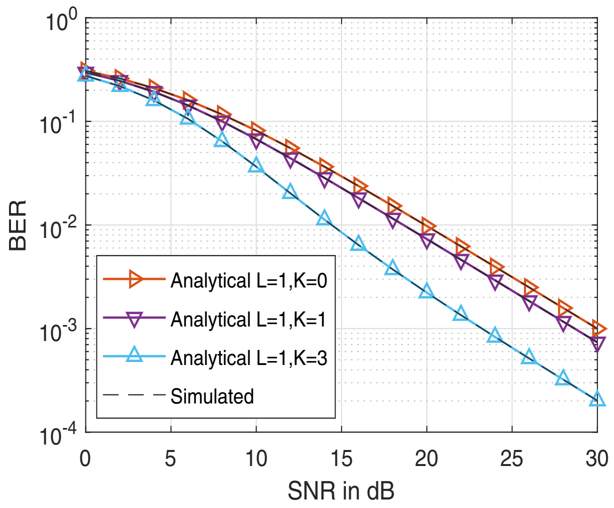

Fig. 2. DF for single antenna UAV node considering $\delta_{sr} = \delta_{rd} = 1$ & $K_{sr} = K_{rd} = K$

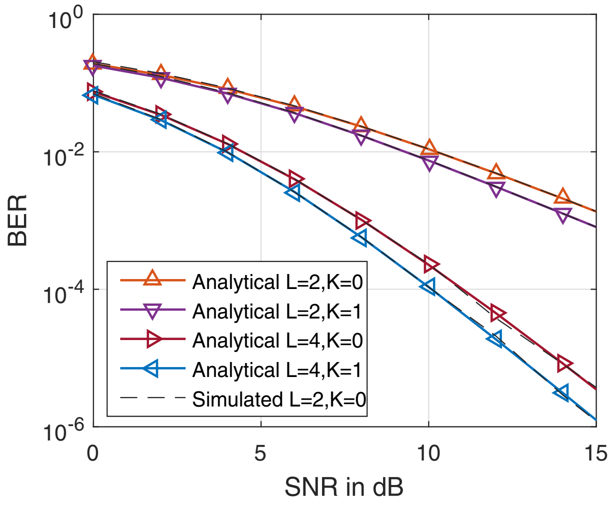

Fig. 3. DF for multiple antenna UAV node considering $\delta_{sr} = \delta_{rd} = 1$ & $K_{s,r} = K_{r,d} = K$.

should also increase. The close match between the analytical and simulation results validates the correctness of the derived closed-form expressions. Fig. 3 depicts the average BER performance of the considered system for L=$[2, 4]$ antennas at the UAV node and the channel variance $\delta_{sr} = \delta_{rd} = 1$

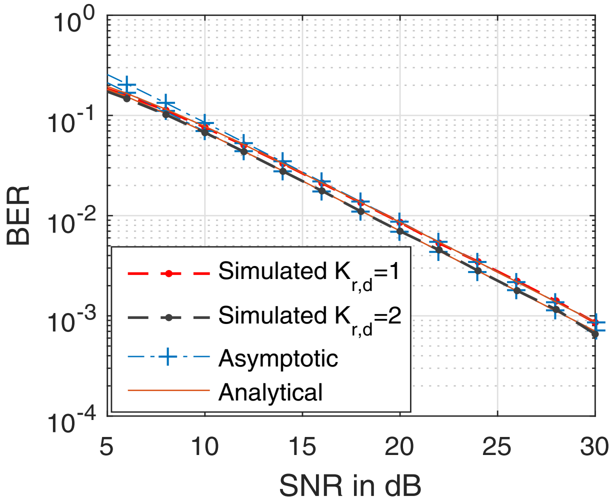

Fig. 4. DF for single antenna UAV node considering $\delta_{sr} = \delta_{rd} = 1$ for Rician-factor $K_{s,r} = 0$ & $K_{r,d} = [1, 2]$.

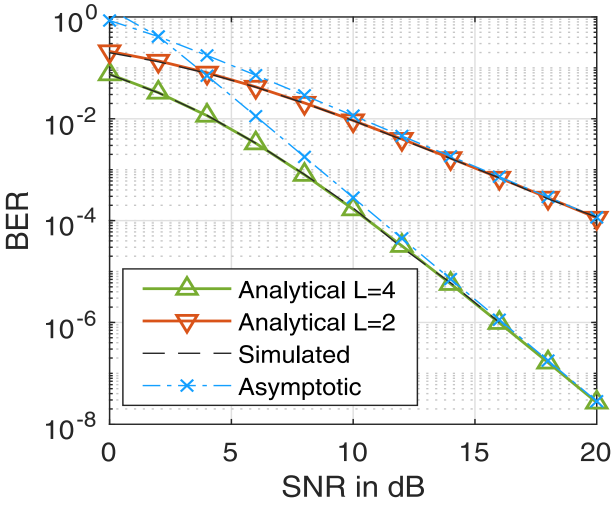

Fig. 5. DF for multiple antenna UAV node considering $\delta_{sr} = \delta_{rd} = 1$ for Rician-factor $K_{sr} = 0$ & $K_{rd} = 1$.

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for the symmetric Rice-factor K=$[0,1]$. It is observed from the result that increasing in the number of receiving antennas improves the system performance. Thus, we can see the effect of diversity gain with increase in number of links.

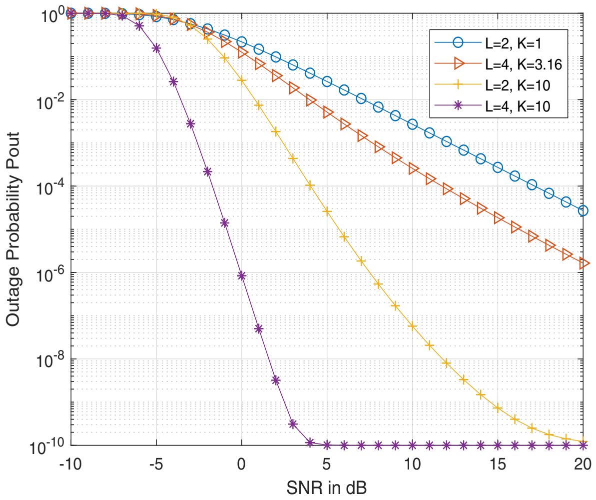

Fig. 6. Outage Probability of the considered UAV aided system with multiple antennas

Fig. 4 shows the average BER and asymptotic performance for BPSK signalling for single antenna configuration with asymmetric Rice factor values $K_{sr} = 1, K_{rd} = 2$ and channel variance $\delta_{sr} = \delta_{rd} = 1$. It validates performance improvement with increase in Rice factor K to about $1-2$ dB for error of 10^{-3}.

Fig. 5 shows the average BER performance of the considered system with L=[2,4] antennas at the UAV node and the channel variance $\delta_{sr} = \delta_{rd} = 1$ for the asymmetric Rice-factor $K_{sr} = 0$ and $K_{rd} = 1$. It is considered that the model behaves as Rayleigh faded channel from Source to UAV and Rician faded channel from UAV to destination as UAV is far from the source and near to the destination thus there exists NLOS component from source to UAV and LOS from UAV to destination. It is observed that as UAV reaches nearer to the user the power of the LOS component increases and leads to better system performance. The performance enhancement by 10 dB can clearly be seen as K_{rd} increases from 0 to 1 for the error floor of 10^{-4} .

Fig. 6 presents the performance of the considered system in terms of the outage probability with respect to SNR. It is observed that as the number of antennas is getting increased resulting to diversity gain, the system performance also improves. Further, we also observe the outage performance for different TWDP faded channel conditions.

V. CONCLUSION

In this paper, the closed-form expression of the average BER for the considered UAV assisted relayed system in multiple link scenario over TWDP fading with symmetric and asymmetric channel conditions is derived. Further, asymptotic analysis is perfomed to get the better insight of the system. Also, all the derived analytical results are verified with the help of simulation results.

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