Performance Analysis of Multiantenna Two-Way Relay Network With Co-Channel Interference

Imtiyaz Khan*, Krishna Kanth Dhulipudi † and Poonam Singh‡
Department of Electronics and Communication Engineering, NIT Rourkela, India
Email: *imtiyazfaith@gmail.com, †krishnakanthdulipudi@gmail.com, ‡psingh@nitrkl.ac.in

***Abstract*—This paper presents the performance analysis of the multiple antenna two-way amplify and-forward (AF) relay network in an interference-limited environment. Multiple antenna system is considered to overcome the fading effect. To avoid the high feedback overhead and fully exploit multiple antenna diversity, we employ transmit antenna selection (TAS) at the user node and analog network coding (ANC) at relaying node. We are assuming the presence of multiple co-channel interference (CCI) at the AF relay and noisy sources, an approximate closed-form expression for the overall outage probability (OOP) is derived. To gain more insight into system performance high SNR analysis is done and asymptotic expression for OOP is obtained. Furthermore, upper bound on ergodic capacity (EC) and approximate expression for symbol error probability(SEP) are derived. The tightness of our analysis is attested through Monte Carlo simulation and provides the insight into the impact of CCI under the general operating conditions and the key system parameters on overall system performance.**

***Index Terms*—Two-way relay systems, co-channel interferences, multi-antenna, AF relaying, overall outage probability, asymptotic analysis, symbol error probability, ergodic capacity.**

I. INTRODUCTION

In last decade, cooperative communication has gained significant research attention due to their ability to provide an extended coverage area and enhanced throughput additionally with reduced power consumption [1]. It has been extensively deployed in recent wireless standards such as long term evolution-advanced (LTE-A) and IEEE 802.16j [2]. Due to increase in data rate, there is a high demand of frequency spectrum which allows the frequency reuse for better spectrum efficiency. Thus, the intercell co-channel interference (CCI) turns out to be the dominant factor on the deployment of wireless relaying transmission [3]–[7]. Due to limited throughput of one-way relaying (OWR) protocol, two-way relaying (TWR) protocol is proposed [8]. Due to heavy spectrum reuse, TWR system is also affected by CCI. To address this issue many works have been done [9]–[13]. In [9], authors studied interference limited systems over Rayleigh fading channels. In [10], authors have done the approximate analysis of TWR amplify-and-forward (AF) relaying system in Nakagami-m fading channel, where CCI is assumed at the relay. In [11], authors examined the performance of AF fixed gain TWR system, where interference is assumed at the two end sources over Nakagami-m fading channel. In [12], authors have evaluated the lower bound on the performance of AF TWR system, where interference is subjected to all the nodes over Nakagami-m fading channel. Recently, authors in [13] have adressed the issue of CCI in spectrum sharing scenario, where performance analysis is done for decode-and-forward (DF) TWR cognitive radio system. All of the above-mentioned work has been done using a single antenna at all the terminal.

In addition to TWR system, multiple antenna has also gained a lot of research interest due to its ability to improve the system throughput against multipath fading severity. Multiple antenna deployments in fixed gain AF relay systems can improve the system throughput at a low practical implementation complexity. In multiantenna systems, beamforming or transmit antenna selection (TAS) is used to improve the system throughput [14]. Former requires full channel state information (CSI) at the transmitter, while the latter requires only few information about the selection index which can be fulfilled via a low-rate feedback channel. Therefore, TAS strategy is more efficient than its counterpart with the performance tradeoff [15]. In this work, we use TAS strategy at two end users, i.e., to maximize the received signal-to-noise ratio (SNR), each end user selects the strongest antenna for transmission. In [16], authors have addressed the issue of CCI in the multiantenna system.

In the context of interference-limited AF-TWR systems, highlighted differences between the work presented here and [10], [12], [16] and [17] are:

1) In [10] and [12], only single antenna is used. Additionally [12] provides only the bounds on the system performance.
2) In [16], beamforming is used among the terminals and the individual outage probability is evaluated in Rayleigh fading environment.
3) In [17] multi-antenna beamforming is used to evaluate the single user performance of interference limited system for fixed gain relaying.

The main aim of this paper is to analyze the overall system performance of TAS based system affected by CCI. These systems may suffer from severe performance degradation, which is not addressed in multiantenna scenario for TWR system. Our main contributions are summarized as follows:

- We examine a multi-antenna TWR system, where the relay node is affected by CCI[1]. The considered framework has been barely addressed. We have assumed that

[1]This scenario is practical in the sense when the the relay node is located near to the cell edge, whereas the two sources are placed at the center of adjacent cells

all channels follows Rayleigh fading. Furthermore, a tight approximate expression of overall outage probability (OOP) is derived.

- The effects on end-to-end system performance by number of interferers at the relay node and the number of transmit antennas at both end sources are examined. Numerical illustrations validate our analysis with the help of Monte-Carlo simulation.
- To gain more insights into the main system parameters, we present the high SNR analysis and asymptotic expression of OOP is derived.
- We analyze the symbol error probability (SEP) performance by using the cumulative distribution function (CDF) based method and approximate closed form expression is derived.
- Using Jensen's inequality, we obtained the upper bound expression of ergodic capacity (EC) for the considered system.

Notations: Absolute value is denoted by $|\cdot|$. $\mathcal{CN}(\mu, \sigma^2)$ denotes a complex circular Gaussian random variable with mean μ and variance σ^2. $\Gamma(\cdot)$ represents the complete gamma functions [18, Eq. (8.350)]. $\mathbb{E}[\cdot]$ shows the expectation.

II. System and Channel Model

We consider an AF cellular relay network, which consists of a base station (BS) that tries to communicate with the mobile station (MS) via relay ($\mathcal{R}$) as shown in Fig. 1. The BS and MS are equipped with L and M antennas respectively, whereas $\mathcal{R}$ is equipped with a single antenna. We assumed that due to heavy path loss or shadowing, there is no direct path between the MS and the BS. All terminals are further assumed to communicate in half duplex mode. Here on, we refer to the BS and MS as terminals $\mathtt{S}_1$ and $\mathtt{S}_2$ respectively.

We further assume a Rayleigh block fading scenario, where the channel fading coefficient between any terminal $\mathtt{S_i}$ is h_i, where $i \in \{1_l, 2_m\}$, $m \in \{1, 2, \ldots, M\}$ and $l \in \{1, 2, \ldots, L\}$. The channel magnitude $|h_i|$ is Rayleigh distributed, such that the channel gain $|h_i|^2$ is exponentially distributed. Here, we consider a scenario in which the AF relay is interfered with K co-channel interferes I_q $(q = 1, .., K)$.

Using a single antenna, user $\mathtt{S}_1$ transmits s_1 to $\mathcal{R}$, and user $\mathtt{S}_2$ transmits s_2 to $\mathcal{R}$ with power P_{S_1} and P_{S_2} respectively. At end users, the antenna which maximizes the instantaneous received signal-to-interference-noise ratio (SINR) at $\mathcal{R}$ is selected. In first transmission phase (MAC phase which is represented by dashed line in Fig. 1), thus the received signal at $\mathcal{R}$ is given by

$$y_R = \sqrt{P_{S_1}} h_{1_{l^*}} s_1 + \sqrt{P_{S_2}} h_{2_{m^*}} s_2 + \sum_{q=1}^{K} \sqrt{P_{I,q}} g_q x_q + n_R, \tag{1}$$

where n_R is the additive white Gaussian noise (AWGN) noise received at $\mathcal{R}$, $P_{I,q}$ is the power of q_{th} interfering signal, g_q is the fading coefficient and x_q is the message signal of q_{th} interferer, $|h_{1_{l^*}}| = \max_{1 \le l \le L} |h_{1_l}|$ and $|h_{2_{m^*}}| = \max_{1 \le m \le M} |h_{2_m}|$

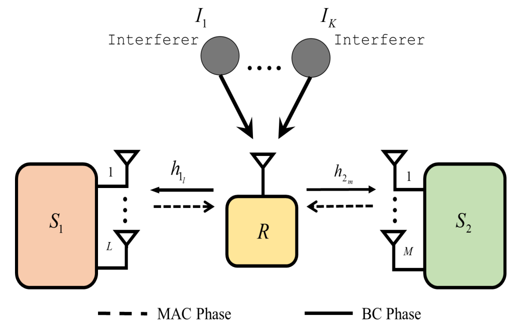

Fig. 1. Multi-antenna two-way AF relaying

denotes the magnitude of the fading coefficient between $\mathtt{S}_1$ & $\mathcal{R}$, and the magnitude of the fading coefficient between $\mathtt{S}_2$ & $\mathcal{R}$ of selected antenna respectively.

In the second transmission phase (BC phase, which is represented by solid lines in Fig. 1), $\mathcal{R}$ applies the scaling gain G to y_R and forwards it to both $\mathtt{S}_1$ and $\mathtt{S}_2$ with power P_R. Thus the received signal at $\mathtt{S}_1$ and $\mathtt{S}_2$ terminal is given as

$$y_{S_1} = G h_{1_{l^*}} y_R + n_{S_1} \tag{2}$$

$$y_{S_2} = G h_{2_{m^*}} y_R + n_{S_2}, \tag{3}$$

where, G defines the variable gain of relay which is given as[2] $G^2 = P_R/(P_{S_1} |h_{1_{l^*}}|^2 + P_{S_2} |h_{2_{m^*}}|^2 + \sum_{q=1}^{K} P_{I,q} |g_q|^2 + N_0)$ By substituting y_R from (1) in (2) and (3) we get

$$\begin{aligned} y_{S_1} &= G\sqrt{P_{S_1}} h_{1_{l^*}} h_{1_{l^*}} s_1 + G\sqrt{P_{S_2}} h_{1_{l^*}} h_{2_{m^*}} s_2 \\ &+ G h_{1_{l^*}} n_R + G h_{1_{l^*}} \sum_{q=1}^{K} \sqrt{P_{I,q}} g_q x_q + n_{S_1} \end{aligned} \tag{4}$$

$$\begin{aligned} y_{S_2} &= G\sqrt{P_{S_1}} h_{1_{l^*}} h_{2_{m^*}} s_1 + G\sqrt{P_{S_2}} h_{2_{m^*}} h_{2_{m^*}} s_2 \\ &+ G h_{2_{m^*}} n_R + G h_{2_{m^*}} \sum_{q=1}^{K} \sqrt{P_{I,q}} g_q x_q + + n_{S_2}. \end{aligned} \tag{5}$$

After canceling the self interference term from y_{S_1} and y_{S_2} leads to

$$\begin{aligned} y^*_{S_1} &= G\sqrt{P_{S_2}} h_{1_{l^*}} h_{2_{m^*}} s_2 + G h_{1_{l^*}} n_R \\ & G h_{1_{l^*}} \sum_{q=1}^{K} \sqrt{P_{I,q}} g_q x_q + n_{S_1} \end{aligned} \tag{6}$$

$$\begin{aligned} y^*_{S_2} &= G\sqrt{P_{S_1}} h_{1_{l^*}} h_{2_{m^*}} s_1 + G h_{2_{m^*}} n_R \\ & G h_{2_{m^*}} \sum_{q=1}^{K} \sqrt{P_{I,q}} g_q x_q + + n_{S_2}. \end{aligned} \tag{7}$$

Thus, the received SINR at two terminal $\mathtt{S}_1$ and $\mathtt{S}_2$ are given as

$$\gamma_{S_1 \to S_2} = \frac{P_R P_{S_1} X_l Y_m}{P_{S_1} N_0 X_l + Y_m (P_R (N_0 + Z) + P_{S_2} N_0)} \tag{8}$$

[2]Without loss of generality we have assumed that the noise at all the terminal (n_R, n_{S_1}, n_{S_2}) follows $\mathcal{CN}(0, N_0)$.

$$\gamma_{S_2 \to S_1} = \frac{P_R P_{S_2} X_l Y_m}{X_l(P_R(N_0 + Z) + P_{S_1} N_0) + P_{S_2} N_0 Y_m}, \quad (9)$$

where $X_l = |h_{1_{l^*}}|^2$, $Y_m = |h_{2_{m^*}}|^2$ and $Z = \sum_{q=1}^{K} P_{I,q}|g_q|^2$. Thus, based on (8) and (9), the OOP, SEP and EC is formulated in next section.

III. Performance Analysis

In this section, we analyze the performance of the proposed system model. An approximate expression for OOP and SEP is derived. Furthermore, closed form expression for upper bounded EC is obtained.

A. Overall Outage Probability (OOP)

OOP of a system can be defined as the probability with which the instantaneous end to end SINR $\gamma_{e2e} = \min(\gamma_{S_1 \to S_2}, \gamma_{S_2 \to S_1})$, drops below a predefined threshold γ_{th}. However, since $\gamma_{S_1 \to S_2}$ and $\gamma_{S_2 \to S_1}$ are not independent, thus the analysis for TWR case is more involved. It was shown in [19] that $\gamma_{S_1 \to S_2} > \gamma_{S_2 \to S_1}$ for $Y_m < X_l$ and $\gamma_{S_1 \to S_2} < \gamma_{S_2 \to S_1}$ for $Y_m > X_l$. Thus, overall outage probability is given as

$$\begin{aligned} \mathcal{P}_{out}(\gamma_{th}) &= \Pr(\gamma_{e2e} < \gamma_{th}) \\ &= 1 - \Pr(\gamma_{S_1 \to S_2} > \gamma_{th}, \gamma_{S_2 \to S_1} > \gamma_{th}) \\ &= 1 - \Pr(\gamma_{S_2 \to S_1} > \gamma_{th} | Y_m < X_l) \\ &\quad - \Pr(\gamma_{S_1 \to S_2} > \gamma_{th} | Y_m > X_l) \\ &= 1 - \Pr_1 - \Pr_2, \end{aligned} \quad (10)$$

whereas for a given transmission rate R_S, $\gamma_{th} = 2^{R_S} - 1$, is the SNR threshold. Expression for $\Pr_1$ and $\Pr_2$ are given in (17) and (18) at the top of the next page and the derivation of $\Pr_1$ is given in Appendix.

B. Asymptotic Analysis

The approximate expression of OOP obtained in previous section is too complicated to make the relationship between system parameters and OOP. To gain better insight, here we present asymptotic expression of (10). Applying the first order Taylor series expansions $e^{-x} \approx (1-x)$ and $(1+x)^{-1} \approx (1-x)$ into (10) by neglecting the higher order terms we get

$$\mathcal{P}_{out}^{\infty}(\gamma_{th}) = 1 - \Pr_1^{\infty} - \Pr_2^{\infty}, \quad (11)$$

where, $\Pr_1^{\infty}$ and $\Pr_2^{\infty}$ are given in (19) and (20) respectively.

Using the fact, $\sum_{j=0}^{M-1} \binom{M}{j+1} (-1)^j = 1$ and assuming $P_S = P_{S_1} = P_{S_2}$. As a result (11) can be further written as (12), where $\propto$ represents "proportional to". Thus

$$\mathcal{P}_{out}^{\infty}(\gamma_{th}) \propto \left(1 - e^{\frac{-\gamma_{th} K P_I \Omega_I}{P_S \Omega_x}}\right)^L + \left(1 - e^{\frac{-\gamma_{th} K P_I \Omega_I}{P_S \Omega_y}}\right)^M. \quad (12)$$

From the above expression, we can deduce that the achievable diversity order depends on the interference power level. If P_I remain fixed on condition $P_I \ll P_S$, than the achievable diversity order of the proposed system is $\min(L, M)$. However, when P_I increases to the same level of P_S so that $\frac{P_S}{P_I}$ remains constant, the diversity order is reduced to zero, which is in consent with [12].

C. Symbol Error Probability (SEP)

The symbol error probability (SEP) plays an important role in deciding the maximum transmission rate. The SEP is obtained by using the formulae $\mathbb{E}[\alpha Q(\sqrt{2\beta\gamma_{e2e}})]$, where $Q(x)$ is complimentary error function and α, β are arbitrary constants which depend on modulation type. Mostly in literature, the CDF based approach is used for evaluating the SEP. The SEP can be derived by substituting the CDF of overall SINR in given formula

$$P_e = \frac{\alpha}{2}\sqrt{\frac{\beta}{\pi}} \int_0^{\infty} \frac{e^{-d\gamma}}{\sqrt{\gamma}} F_{\gamma_{e2e}}(\gamma) d\gamma, \quad (13)$$

where $F_{\gamma_{e2e}}(\gamma)$ is the CDF of γ_{e2e} which can easily obtained from OOP expression given in (10) by interchanging γ_{th} to γ. We will use following identity while deriving the expression for SEP

$$\int_{x=0}^{\infty} \frac{x^{\mu} e^{-sx}}{(x+z)^{\upsilon}} dx = \Gamma(\mu+1) z^{\mu-\upsilon+1} \psi(\mu+1, \mu-\upsilon+2; sz), \quad (14)$$

where $\psi(.;.;.)$ is Tricomi confluent hypergeometric function defined in [18, Eq. (9.210.2)]. Furthermore, by using the fact ${}_2F_0(\upsilon, \rho; ; -1/\sigma) = \sigma^{\upsilon} \psi(\upsilon, \upsilon - \rho + 1; \sigma)$ and after some mathematical manipulation we will obtain the approximate close form expression of SEP given in(22), where ${}_2F_0(\cdot, \cdot; ; \cdot)$ is generalised hypergeometric function.

D. Ergodic Capacity (EC)

Here, we focus on deriving the EC of the considered system by taking multiple interferences at the relay node. From [8], we know that EC can be calculated as $C = 0.5\mathbb{E}[\log_2(1 + \gamma_{e2e})]$, where 0.5 implies that the entire communication is done in two time slots. By invoking Jensen's inequality, the upper bound for the EC can be obtained as

$$C \leq C^{up} = \frac{1}{2}\log_2(1 + \mathbb{E}[\gamma_{e2e}]), \quad (15)$$

where the expectation of γ_{e2e} can be easily solved by using CDF based approach

$$\mathbb{E}[\gamma_{e2e}] = \int_0^{\infty} (1 - F_{\gamma_{e2e}}(\gamma)) d\gamma. \quad (16)$$

Now substituting the CDF of γ_{e2e} into (16) and apply the identity given in (14). After some mathematical manipulation, we will obtain expression given in (23). Finally, after substituting (23) into (15), we will obtain the upper bounds expression of EC.

$$\mathrm{Pr}_1 \approx \frac{LM}{\Omega_x (P_I\Omega_I)^K} \sum_{i=0}^{L-1}\sum_{j=0}^{M-1} \frac{1}{(j+1)} \binom{L-1}{i}\binom{M-1}{j} (-1)^{i+j} \left\{ \frac{\Omega_x}{(i+1)} e^{-\frac{\gamma_{th}}{P_{S_2}P_R}\left[\left(\frac{i+1}{\Omega_x}+\frac{j+1}{\Omega_y}\right)\mathcal{P}_2 + \frac{P_{S_2}N_0(j+1)}{\Omega_x}\right]} \right.$$
$$\left. \times \left(\frac{\gamma_{th}}{P_{S_2}}\left(\frac{i+1}{\Omega_x}+\frac{j+1}{\Omega_y}\right)+\frac{1}{P_I\Omega_I}\right)^{-K} - \left(\frac{i+1}{\Omega_x}+\frac{j+1}{\Omega_y}\right)^{-1} e^{-\frac{\gamma_{th}\mathcal{P}_1}{P_{S_2}P_R}\left(\frac{i+1}{\Omega_x}+\frac{j+1}{\Omega_y}\right)} \left(\frac{\gamma_{th}}{P_{S_2}}\left(\frac{i+1}{\Omega_x}+\frac{j+1}{\Omega_y}\right)+\frac{1}{P_I\Omega_I}\right)^{-K}\right\} \tag{17}$$

$$\mathrm{Pr}_2 \approx \frac{LM}{\Omega_y (P_I\Omega_I)^K} \sum_{i=0}^{L-1}\sum_{j=0}^{M-1} \frac{1}{(i+1)} \binom{L-1}{i}\binom{M-1}{j} (-1)^{i+j} \left\{ \frac{\Omega_y}{(j+1)} e^{-\frac{\gamma_{th}}{P_{S_1}P_R}\left[\left(\frac{i+1}{\Omega_x}+\frac{j+1}{\Omega_y}\right)\mathcal{P}_3 + \frac{P_{S_1}N_0(j+1)}{\Omega_y}\right]} \right.$$
$$\left. \times \left(\frac{\gamma_{th}}{P_{S_1}}\left(\frac{i+1}{\Omega_x}+\frac{j+1}{\Omega_y}\right)+\frac{1}{P_I\Omega_I}\right)^{-K} - \left(\frac{i+1}{\Omega_x}+\frac{j+1}{\Omega_y}\right)^{-1} e^{-\frac{\gamma_{th}\mathcal{P}_1}{P_{S_1}P_R}\left(\frac{i+1}{\Omega_x}+\frac{j+1}{\Omega_y}\right)} \left(\frac{\gamma_{th}}{P_{S_1}}\left(\frac{i+1}{\Omega_x}+\frac{j+1}{\Omega_y}\right)+\frac{1}{P_I\Omega_I}\right)^{-K}\right\} \tag{18}$$

$$\mathrm{Pr}_1^{\infty} \approx \frac{LM}{\Omega_x} \sum_{i=0}^{L-1}\sum_{j=0}^{M-1} \frac{1}{(j+1)} \binom{L-1}{i}\binom{M-1}{j} (-1)^{i+j} \left\{ \frac{\Omega_x}{(i+1)} \left(1 - \frac{\gamma_{th}}{P_{S_2}P_R}\left[\mathcal{T}_{ij}\mathcal{P}_2 + \frac{P_{S_2}N_0(i+1)}{\Omega_x}\right] - \frac{\gamma_{th}K\mathcal{T}_{ij}P_I\Omega_I}{P_{S_2}}\right) \right.$$
$$\left. - \mathcal{T}_{ij}{}^{-1}\left(1 - \frac{\gamma_{th}\mathcal{T}_{ij}\mathcal{P}_1}{P_{S_2}P_R} - \frac{\gamma_{th}\mathcal{T}_{ij}KP_I\Omega_I}{P_{S_2}}\right)\right\} \tag{19}$$

$$\mathrm{Pr}_2^{\infty} \approx \frac{LM}{\Omega_y} \sum_{i=0}^{L-1}\sum_{j=0}^{M-1} \frac{1}{(i+1)} \binom{L-1}{i}\binom{M-1}{j} (-1)^{i+j} \left\{ \frac{\Omega_y}{(j+1)} \left(1 - \frac{\gamma_{th}}{P_{S_1}P_R}\left[\mathcal{T}_{ij}\mathcal{P}_3 + \frac{P_{S_1}N_0(j+1)}{\Omega_y}\right] - \frac{\gamma_{th}K\mathcal{T}_{ij}P_I\Omega_I}{P_{S_1}}\right) \right.$$
$$\left. - \mathcal{T}_{ij}{}^{-1}\left(1 - \frac{\gamma_{th}\mathcal{T}_{ij}\mathcal{P}_1}{P_{S_1}P_R} - \frac{\gamma_{th}\mathcal{T}_{ij}KP_I\Omega_I}{P_{S_1}}\right)\right\} \tag{20}$$

$$\begin{aligned} \mathcal{D} &= \frac{1}{P_{S_2}P_R}\left[\mathcal{T}_{ij}(P_RN_0 + P_{S1}N_0) + \frac{P_{S_2}N_0(i+1)}{\Omega_x}\right] & \mathcal{F} &= \frac{\mathcal{T}_{ij}}{P_{S_2}P_R}[P_RN_0 + P_{S1}N_0 + P_{S_2}N_0] \\ \mathcal{E} &= \frac{1}{P_{S_1}P_R}\left[\mathcal{T}_{ij}(P_RN_0 + P_{S_2}N_0) + \frac{P_{S_1}N_0(j+1)}{\Omega_y}\right] & \mathcal{H} &= \frac{\mathcal{T}_{ij}}{P_{S_1}P_R}[P_RN_0 + P_{S1}N_0 + P_{S_2}N_0] \end{aligned} \tag{21}$$

$$P_e = \frac{\alpha}{2} - \frac{\alpha\sqrt{\beta}}{2}\frac{LM}{\Omega_x\Omega_y}\sum_{i=0}^{L-1}\sum_{j=0}^{M-1}\binom{L-1}{i}\binom{M-1}{j}(-1)^{i+j}\left[\frac{\Omega_y}{(j+1)}\left\{\frac{\Omega_x}{(i+1)}\sqrt{\frac{1}{(\beta+\mathcal{D})}}\,{}_2F_0\left(0.5, K;;-\frac{P_I\Omega_I\mathcal{T}_{ij}}{(\beta+\mathcal{D})P_{S_2}}\right)\right.\right.$$
$$\left. -\mathcal{T}_{ij}^{-1}\sqrt{\frac{1}{(\beta+\mathcal{F})}}\,{}_2F_0\left(0.5, K;;-\frac{P_I\Omega_I\mathcal{T}_{ij}}{(\beta+\mathcal{F})P_{S_2}}\right)\right\} + \frac{\Omega_x}{(i+1)}\left\{\frac{\Omega_y}{(j+1)}\sqrt{\frac{1}{(\beta+\mathcal{E})}}\,{}_2F_0\left(0.5, K;;-\frac{P_I\Omega_I\mathcal{T}_{ij}}{(\beta+\mathcal{E})P_{S_1}}\right)\right.$$
$$\left.\left. -\mathcal{T}_{ij}^{-1}\sqrt{\frac{1}{(\beta+\mathcal{H})}}\,{}_2F_0\left(0.5, K;;-\frac{P_I\Omega_I\mathcal{T}_{ij}}{(\beta+\mathcal{H})P_{S_1}}\right)\right\}\right] \tag{22}$$

$$\mathbb{E}[\gamma_{e2e}] = \frac{LM}{\Omega_x\Omega_y}\sum_{i=0}^{L-1}\sum_{j=0}^{M-1}\binom{L-1}{i}\binom{M-1}{j}(-1)^{i+j}\left[\frac{\Omega_y}{(j+1)}\left(\frac{\Omega_x}{(i+1)\mathcal{D}}\,{}_2F_0\left(1, K;;-\frac{P_I\Omega_I\mathcal{T}_{ij}}{\mathcal{D}P_{S_2}}\right) - \frac{1}{\mathcal{T}_{ij}\mathcal{F}}\,{}_2F_0\left(1, K;;-\frac{P_I\Omega_I\mathcal{T}_{ij}}{\mathcal{F}P_{S_2}}\right)\right)\right.$$
$$\left. + \frac{\Omega_x}{(i+1)}\left(\frac{\Omega_y}{(j+1)\mathcal{E}}\,{}_2F_0\left(1, K;;-\frac{P_I\Omega_I\mathcal{T}_{ij}}{\mathcal{E}P_{S_2}}\right) - \frac{1}{\mathcal{T}_{ij}\mathcal{H}}\,{}_2F_0\left(1, K;;-\frac{P_I\Omega_I\mathcal{T}_{ij}}{\mathcal{H}P_{S_2}}\right)\right)\right]. \tag{23}$$

IV. Numerical and Simulation Results

Here, some numerical illustrations are conducted to evaluate the performance of multi-antenna interference limited TWR system. Without loss of generality, the following parameters are considered: γ_{th}=3dB, N_0=1, $\Omega_x = \Omega_y = \Omega_I = 1$ and $P_{S_1} = P_{S_2} = 2P_R = P_S$.

Fig. 2 and 3 illustrate the approximate OOP expression vs. transmit SNR given in (10) of the interference limited multiantenna AF-TWR system. It is clear that the simulation result having a good match with the analytical curve shows the validity of our analysis. We observed that system OOP decreases with increasing L or M in Fig 2 for $K = 3$, while in Fig 3 decreasing number of interferers improves the system

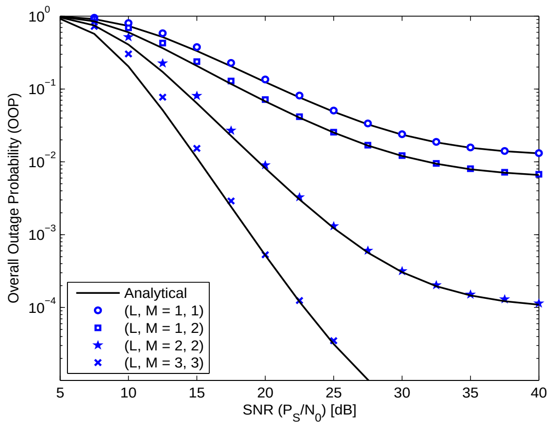

Fig. 2. OOP vs SNR of Multi-antenna TWR system under different system parameter for K=3

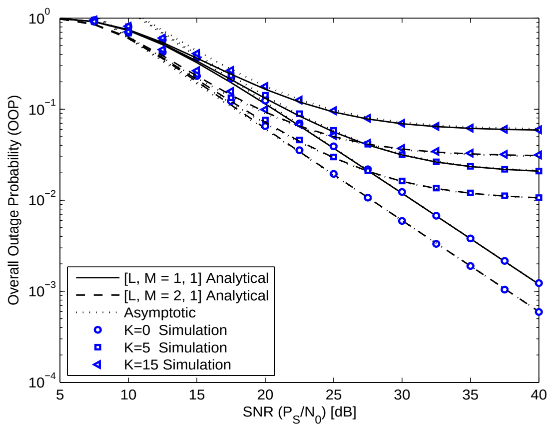

Fig. 3. OOP vs SNR of Multi-antenna TWR system under different practical scenarios

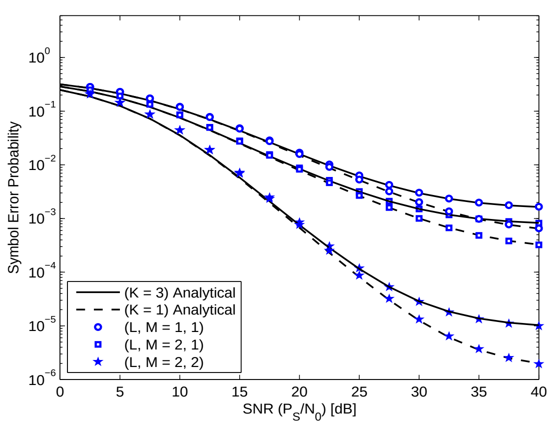

Fig. 4. SEP vs SNR of Multi-antenna TWR system under different practical scenarios

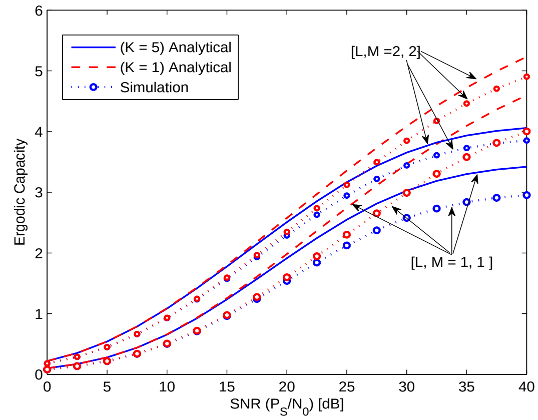

Fig. 5. EC vs SNR of Multi-antenna TWR system under different practical scenarios

performance. Apart from that asymptotic expression given in (11), follow very well with corresponding high SNR. It is visible that in the high SNR range there is a floor effect, due to the impact of co-channel interference.

In Fig. 4, approximated SEP given in (22) for BPSK modulation ($\alpha = \beta = 1$) is plotted as a function of SNR for different values of L, M and K. As observed, by increasing L and M, SEP reduces systematically while increasing K affect in opposite direction. Also, it can be seen that the relative distance between the curves $K = 1$ and $K = 3$ for all system parameters is visible only after $15dB$ SNR. This implies that the impact of the number of interference for each system parameter is less pronounced in low SNR and becomes increasingly dominant in high SNR. This is consistent with the results of [9].

Furthermore Fig. 5 illustrate the EC vs SNR plot of the considered system for the number of interferences and different antenna configurations. Firstly, it is observed that all the simulation results are in good agreement with upper bounded analytical expression given in (23). Likewise the previous results, we can observe the saturation of results at high SNR and thus flooring effect exist due to the presence of CCI.

V. Conclusions

We have analyzed the performance of a multiantenna AF-TWR network in the presence of multiple interferences at relay node over Rayleigh fading channel. New analytical approximated expressions have been derived for the OOP as well as SEP. Likewise, the upper bound of the EC of the considered system is obtained. On the other hand, a simpler asymptotic expression of the OOP is also provided. From our findings, it is clear that the interference present at relay node creates a flooring effect on the system performance and presence of multiple antennas helps to alleviate it. Furthermore, the validity of our theoretical analysis is verified with Monte-Carlo simulations.

Appendix

As mentioned earlier, both X_l and Y_m follow exponential distribution with mean powers $\frac{1}{\Omega_x}$ and $\frac{1}{\Omega_y}$, respectively. Following condition will define the limits of integrals $y > \frac{\gamma_{th} A x}{x - \gamma_{th} B}$ and $x > y$ obtained from (9). Thus, the probability $\Pr_1$ is readily given by

$$\Pr_1 = E_z\left[\int_{x=\gamma_{th}(A+B)}^{\infty}\int_{y=\frac{\gamma_{th}Ax}{x-\gamma_{th}B}}^{y=x} f_{X_{l^*}}(x)\, f_{Y_{m^*}}(y)dxdy\right], \tag{24}$$

where $A = (P_R(N_0+P_I Z)+P_{S_1}N_0)/(P_{S_2}P_R)$, $B = N_0/P_R$

Since multiple integrals are involved in (24) evaluating it in closed-form is not tractable. To make the equation analytically tractable we can assume $\gamma_{th}B$ to be insignificant when transmitting power P_R and P_{S_2} is large. Taking these assumptions the limits reduced to $\gamma_{th}A < y < x$ and $x > \gamma_{th}(A+B)$. Thus we get

$$\Pr_1 \approx \int_0^{\infty}\int_{\gamma_{th}(A+B)}^{\infty}\int_{\gamma_{th}A}^{x} f_{X_{l^*}}(x)\, f_{Y_{m^*}}(y) f_Z(z) dxdydz, \tag{25}$$

where $f_{X_{l^*}}(x)$ and $f_{Y_{m^*}}(y)$ are given as [20]

$$f_{X_{l^*}}(x) = \frac{L}{\Omega_x}\sum_{i=0}^{L-1}\binom{L-1}{i}(-1)^i e^{-\left(\frac{i+1}{\Omega_x}\right)x} \tag{26}$$

$$f_{Y_{m^*}}(y) = \frac{M}{\Omega_y}\sum_{j=0}^{M-1}\binom{M-1}{j}(-1)^j e^{-\left(\frac{j+1}{\Omega_y}\right)y}. \tag{27}$$

To proceed further, as in [9], we consider $P_{I,1} = ... = P_{I,K} = P_I$ and obtain the pdf Z under Rayleigh fading with mean power $\frac{1}{\Omega_I}$ as $f_Z(z) = \frac{z^{K-1}}{\Gamma(K)(P_I\Omega_I)^K} e^{-\frac{z}{P_I\Omega_I}}$. Now Substituting $f_{X_{l^*}}(x)$, $f_{Y_{m^*}}(y)$ and $f_Z(z)$ in (25), we will get

$$\begin{aligned}
\Pr_1 &\approx \int_{z=0}^{\infty}\int_{x=\gamma_{th}(A+B)}^{\infty} f_{X_{l*}}(x)\left(\int_{y=(\gamma_{th}A)}^{x}\frac{M}{\Omega_y}\sum_{j=0}^{M-1}\binom{M-1}{j}\right.\\
&\quad \left.\times (-1)^j e^{-\frac{1}{\Omega_y}(j+1)y} dy\right) f_z(z)dxdz\\
&\approx \frac{M}{(j+1)}\sum_{j=0}^{M-1}\binom{M-1}{j}(-1)^j\\
&\quad \times \int_{z=0}^{\infty}\left(\int_{x=\gamma_{th}(A+B)}^{\infty}\frac{L}{\Omega_x}\sum_{i=0}^{L-1}\binom{L-1}{i}(-1)^i e^{-\left(\frac{i+1}{\Omega_x}\right)x}dx\right)\\
&\quad \times\left(e^{-(j+1)\frac{\gamma_{th}A}{\Omega_y}} - e^{-(j+1)\frac{x}{\Omega_y}}\right) f_z(z)dz\\
&\approx \frac{ML}{\Omega_x}\sum_{i=0}^{L-1}\sum_{j=0}^{M-1}\binom{L-1}{i}\binom{M-1}{j}\frac{(-1)^{i+j}}{(j+1)}\\
&\quad \times\left(\frac{\Omega_x}{(i+1)}\, e^{-\frac{\gamma_{th}}{P_{S_2}P_R}\left(\mathcal{T}_{ij}\mathcal{P}_2+\frac{(i+1)P_{S_2}N_0}{\Omega_x}\right)} - \frac{1}{\mathcal{T}_{ij}}\, e^{-\frac{\gamma_{th}\mathcal{T}_{ij}}{P_{S_2}P_R}\mathcal{P}_1}\right)\\
&\quad \times\int_{z=0}^{\infty} e^{-\frac{\gamma_{th}\mathcal{T}_{ij}}{P_{S_2}}z}\frac{1}{(P_I\Omega_I)^K\Gamma(K)} z^{K-1}e^{-\frac{Z}{P_I\Omega_I}}dz,
\end{aligned} \tag{28}$$

now using the identity [18, Eq. (3.351.3)] and after some mathematical manipulation we will get (17), where $\mathcal{P}_1 = (P_{S_1}+P_{S_2}+P_R)N_0$, $\mathcal{P}_2 = (P_{S_1}+P_R)N_0$, $\mathcal{P}_3 = (P_{S_2}+P_R)N_0$, $\mathcal{T}_{ij} = \left(\frac{i+1}{\Omega_x}+\frac{j+1}{\Omega_y}\right)$. Similarly the probability of $\Pr_2$ can be obtained from (8).

References

[1] J. N. Laneman, D. N. Tse, and G. W. Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," *IEEE Trans. Inf. Theory*, vol. 50, no. 12, pp. 3062–3080, Dec. 2004.

[2] Y. Yang, H. Hu, J. Xu, and G. Mao, "Relay technologies for wimax and lte-advanced mobile systems," *IEEE Commun. Mag.*, vol. 47, no. 10, Oct. 2009.

[3] C. Zhong, S. Jin, and K.-K. Wong, "Dual-hop systems with noisy relay and interference-limited destination," *IEEE Trans. Commun.*, vol. 58, no. 3, 2010.

[4] H. A. Suraweera, H. K. Garg, and A. Nallanathan, "Performance analysis of two hop amplify-and-forward systems with interference at the relay," *IEEE Commun. Lett.*, vol. 14, no. 8, pp. 692–694, 2010.

[5] D. B. da Costa, H. Ding, and J. Ge, "Interference-limited relaying transmissions in dual-hop cooperative networks over nakagami-m fading," *IEEE Commun. Lett.*, vol. 15, no. 5, pp. 503–505, 2011.

[6] G. Zhu, C. Zhong, H. A. Suraweera, Z. Zhang, and C. Yuen, "Outage probability of dual-hop multiple antenna af systems with linear processing in the presence of co-channel interference," *IEEE Trans. Wireless Commun.*, 2014.

[7] J. A. Hussein, S. S. Ikki, S. Boussakta, and C. C. Tsimenidis, "Performance analysis of opportunistic scheduling in dual-hop multiuser underlay cognitive network in the presence of cochannel interference," *IEEE Trans. on Veh. Technol.*, vol. 65, no. 10, pp. 8163–8176, 2016.

[8] R. H. Louie, Y. Li, and B. Vucetic, "Practical physical layer network coding for two-way relay channels: performance analysis and comparison," *IEEE Trans. Wireless Commun.*, vol. 9, no. 2, pp. 764–777, Feb. 2010.

[9] S. S. Ikki and S. Aissa, "Performance analysis of two-way amplify-and-forward relaying in the presence of co-channel interferences," *IEEE Trans. on Commun.*, vol. 60, no. 4, pp. 933–939, 2012.

[10] D. B. da Costa, H. Ding, M. D. Yacoub, and J. Ge, "Two-way relaying in interference-limited af cooperative networks over nakagami-m fading," *IEEE Trans. Veh. Technol.*, vol. 61, no. 8, pp. 3766–3771, 2012.

[11] X. Liang, S. Jin, W. Wang, X. Gao, and K.-K. Wong, "Outage probability of amplify-and-forward two-way relay interference-limited systems," *IEEE Trans. Veh. Technol.*, vol. 61, no. 7, pp. 3038–3049, 2012.

[12] E. Soleimani-Nasab, M. Matthaiou, M. Ardebilipour, and G. K. Karagiannidis, "Two-way af relaying in the presence of co-channel interference," *IEEE Trans. Commun.*, vol. 61, no. 8, pp. 3156–3169, 2013.

[13] S. Hatamnia, S. Vahidian, S. Aïssa, B. Champagne, and M. Ahmadian-Attari, "Network-coded two-way relaying in spectrum-sharing systems with quality-of-service requirements," *IEEE Trans. Veh. Technol.*, vol. 66, no. 2, pp. 1299–1312, 2017.

[14] D. Tse and P. Viswanath, *Fundamentals of wireless communication*. Cambridge university press, 2005.

[15] N. Yang, P. L. Yeoh, M. Elkashlan, I. B. Collings, and Z. Chen, "Two-way relaying with multi-antenna sources: Beamforming and antenna selection," *IEEE Trans. Veh. Technol.*, vol. 61, no. 9, pp. 3996–4008, 2012.

[16] H. Phan, F.-C. Zheng, and T. M. C. Chu, "Physical-layer network coding with multiantenna transceivers in interference limited environments," *IET Commun.*, vol. 10, no. 4, pp. 363–371, 2016.

[17] T. Q. Duong, H. A. Suraweera, H.-J. Zepernick, and C. Yuen, "Beamforming in two-way fixed gain amplify-and-forward relay systems with cci," in *Proc. IEEE ICC*, 2012, pp. 3621–3626.

[18] I. S. Gradshteyn and I. Ryzhik, *Table of Integrals, Series, and Products.* San Diego, CA, USA: Academic Press, 2007.

[19] X. Xu, Y. Cai, C. Cai, and W. Yang, "Overall outage probability of two-way amplify-and-forward relaying in Nakagami-m fading channels," in *IEEE WCSP*, Nov. 2011, pp. 1–4.

[20] H. A. Suraweera, G. K. Karagiannidis, Y. Li, H. K. Garg, A. Nallanathan, and B. Vucetic, "Amplify-and-forward relay transmission with end-to-end antenna selection," in *Proc. IEEE WCNC*. IEEE, 2010, pp. 1–6.