Outage Probability in Opportunity Relaying Cooperative Diversity System over Rayleigh Fading Channels with Interferes

Meirong He^{1, a*} and Chunling Zhang^{1, b}

¹Northwest University for Nationalities, Lanzhou, Gansu, 730030, China

^ahmr@xbmu.edu.cn, ^b383045799@qq.com

*The corresponding author

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Abstract. In this paper, we investigate the outage probability in opportunity relaying system with multiple unequal-power Rayleigh interferes at both relay and destination, the closed form expression for the outage probability is derived. Through simulation, it shows that the whole system outage performance can be improved effectively with multiple selected relays .

Introduction

Cooperative diversity communication has been established as a promising technique to combating fading, improving high-data coverage and reliability required for high transmission in wireless communication. At present, the research of cooperative diversity technique shows that the wireless system's performance can be improved tremendously. However, the cooperative diversity networks will be subjected to channel interference in practice, so channel interference is a important factor that can affect the performance significantly. Recently, channel interference has been consideration in some works. In[1,2]studies the outage performance of dual-hop decode-and-forward (DF) cooperative systems with interference-limited relay in Nakagami-m fading environment. In[3,4,5,6]study the outage and bit-error performance in AF and DF cooperative system with interference-limited destination. And also the performance of cooperative networks with interference at relay and destination is studied in[7,8]. In[9], the author researches conventional and opportunistic relaying with interference at relay and destination, and obtain the upper bound of the error probability.

In this paper, we investigate the outage probability performance of the opportunity relay AF cooperative system with multiple co-channel interferes at relays and destination. And with the respect, the closed-form expression of the outage probability is derived. Through the analysis and simulation, the impact of co-channel interferes on the opportunity relay system can be presented.

System Model

We consider a communication system with multiple interferes at relays and destination. In this system, the source node S communicates with destination D can through two link, the direct link or the indirect link. Through the indirect link ,the relay nodes amplify and forward the received information to the destination. This communication system is divided into two orthogonal time intervals. In first time slot, S sends its symbol s_0 to R_i and D. In second time slot, R_i sends amplified symbol to D. We assume the additive white Gaussian noise (AWGN) terms of all links have zero mean and variance N_0

At the first phase, S sends its symbol s_0 to D and all the L relays R , the L relays and destination node D received the faded and noisy source signal. At the same time, the i^{th} relay received co-channel interfering signals from N_i interfering nodes, the destination D also received

interfering signals from N_D interfering nodes. Therefore, the received signals at destination and the i^{th} relay can be expressed as

$$y_{sd} = \sqrt{P_0} h_{sd} s_0 + \sum_{k=1}^{N_D} \sqrt{P_{L,k}} f_{sd_k} s_k + n_0 \quad (1)$$

$$y_{ri} = \sqrt{P_0} h_i s_0 + \sum_{j=1}^{N_i} \sqrt{P_{R_i}} f_{sr_{i,j}} g_j + n_{ri} \quad (2)$$

Where P_0 is the transmit power of S, h_{sd}, h_i are the Rayleigh fading coefficients, $f_{sr_{i,j}}$ are the Rayleigh fading coefficients of the j^{th} interference channel at the i^{th} relay node. f_{sd_k} are the Rayleigh fading coefficients of the k^{th} interference channel at the destination. s_k, g_j are the k^{th}, j^{th} co-channel interferer's signal which can affect the destination and relay. $P_{L,k}, P_{R_i,j}$ are the energy of the k^{th}, j^{th} interference signal at destination and the i^{th} relay respectively. n_0, n_{ri} are the AWGN at the destination and the i^{th} relay.

At the second phase, the relays will amplify and forward the received signal from the source node to the destination with a fixed gain G_i . So the destination's received signal can express as

$$y_{R_i,D} = h_{ri,d} G_i y_{ri} + \sum_{l=1}^{M_i} \sqrt{P_{D_i}} f_{r_i,d_l} c_{i,l} + n_{ri,d} \quad (3)$$

Where $h_{ri,d}$ is the Rayleigh fading coefficients, f_{r_i,d_l} is the Rayleigh fading coefficients of the l^{th} interference channel when the destination receives the i^{th} relay's information. $c_{i,l}$ is the l^{th} co-channel interferers' signal affects the i^{th} relay signal at the destination. $n_{ri,d}$ is the AWGN at the destination. G_i can be expressed as

$$G_i = \sqrt{\frac{P_{r_i}}{P_0 |h_i|^2 + \sum_{j=1}^{N_i} P_{R_i} |f_{sr_{i,j}}|^2 + N_0}} \quad (4)$$

Where P_{r_i} is the transmit power of the i^{th} relay. In opportunity relaying cooperative system, the destination will receive the signal from only one link which has the highest SINR at the destination.

As a result, if the destination receives the signal from the direct link, the SINR at D can be expressed as

$$\gamma_s = \frac{P_0 |h_{sd}|^2}{\sum_{k=1}^{N_b} P_{1,k} |f_{s,d_k}|^2 + N_0} \quad (5)$$

If the destination receives the signal from the i^{th} indirect link, the SINR at D can be expressed as

$$\gamma_{bi} = \frac{P_0 G_i^2 |h_{ri,d}|^2 |h_i|^2}{G_i^2 |h_{ri,d}|^2 \left(\sum_{j=1}^{N_i} P_{R_i} |f_{sr_{i,j}}|^2 + N_0 \right) + \sum_{l=1}^{M_i} P_{D,l} |f_{r_i,d_l}|^2 + N_0} \quad (6)$$

We define $\gamma_0 = \frac{P_0 |h_{sd}|^2}{N_0}$, $\gamma_I = \sum_{k=1}^{N_b} P_{1,k} \frac{|f_{s,d_k}|^2}{N_0}$, $\gamma_{1,i} = \frac{P_0}{N_0} |h_i|^2$, $\gamma_{2,i} = \frac{P_{R_i}}{N_0} |h_{ri,d}|^2$, $\gamma_{R_i} = \sum_{j=1}^{N_i} P_{R_i,j} \frac{|f_{sr_{i,j}}|^2}{N_0}$,

$\gamma_{D_i} = \sum_{l=1}^{M_i} P_{D,l} \frac{|f_{r_i,d_l}|^2}{\sigma_d^2}$, and $C_i = P_0 \frac{\Omega_{sr_i}}{N_0} + \sum_{j=1}^{N_i} P_{R_i,j} \frac{\Omega_j}{N_0} + 1$. Where $\Omega_{sr_i} = E[|h_i|^2]$, $\Omega_j = E[|f_{sr_{i,j}}|^2]$, The

expectation operator is $E[\cdot]$. Above all, γ_s and γ_{bi} can be expressed as

$$\gamma_s = \frac{\gamma_0}{\gamma_I + 1} \quad (7)$$

$$\gamma_{bi} = \frac{\gamma_{1,i} \gamma_{2,i}}{\gamma_{2,i} \gamma_{R_i} + C_i \gamma_{D_i}} \quad (8)$$

$h_{sd}, h_i, |h_{ri,d}|$ are zero-mean complex Gaussian variables, so the probability density function (PDF) of the corresponding signal-to-noise ratio (SNR) $\gamma_0, \gamma_{1,i}, \gamma_{2,i}$ ($i=1, 2, \dots, L$), is all given as

$$f_\gamma(\gamma) = \frac{1}{\bar{\gamma}} \exp\left(-\frac{\gamma}{\bar{\gamma}}\right) \quad (9)$$

System Performance Analysis

From the second part we can know the destination will receive the source signal from only one link: direct link and indirect link which can be decided by the SINR at the destination in the opportunity relaying system. And the link with the highest SINR at the destination will be choose. So the outage probability of this system can be expressed as

$$P_{out} = \Pr(\max(\gamma_s, \gamma_{b1}, \gamma_{b2}, \dots, \gamma_{bL}) < \gamma_{th}) = F_{\gamma_s}(\gamma_{th}) \prod_{i=1}^L F_{\gamma_{bi}}(\gamma_{th}) \quad (10)$$

For calculating Eq. 10, we need study the PDF of $\gamma_{R_i}, \gamma_{D_i}$ and γ_I . From paper [4], the PDF

of $\gamma_{R_i}, \gamma_{D_i}$ and γ_I all can be shown as

$$f_\gamma(\gamma) = \sum_{i=1}^{\rho(A)} \sum_{j=1}^{\tau_i(A)} \chi_{i,j}(A) \frac{P_i^{-j}}{(j-1)!} \gamma^{j-1} \exp\left(-\frac{\gamma}{P_i}\right) \quad (11)$$

Where $A = \text{diag} \left(\frac{P_1}{N_0^2} \Omega_1, \frac{P_2}{N_0^2} \Omega_2, \dots, \frac{P_N}{N_0^2} \Omega_N \right)$, $\rho(A)$ denotes the number of distinct diagonal elements of A , $P_1 > P_2 > \dots > P_{[\rho(A)]}$ are the distinct diagonal elements in decreasing order, $\tau_i(A)$ is the multiplicity of P_i , and $\chi_{i,j}(A)$ is the (i,j) th characteristic coefficient of A .

With the help of Eq. 9, Eq. 11 and the integral formula [10, Eq. (3.351.3)], $F_{\gamma_s}(\gamma_{th})$ can be formulated as

$$\begin{aligned} F_{\gamma_s}(\gamma_{th}) &= \Pr \left(\frac{\gamma_0}{1 + \gamma_I} < \gamma_{th} \right) \\ &= 1 - \int_0^\infty \exp \left(-\frac{(1 + \gamma_I)}{\gamma_0} \gamma_{th} \right) f_{\gamma_I}(\gamma_I) d\gamma_I \\ &= 1 - \exp \left(-\frac{\gamma_{th}}{\gamma_0} \right) \times \sum_{k=1}^{\rho(A)} \sum_{g=1}^{\tau_k(A)} \chi_{k,g}(A) \left(\frac{\gamma_{th}}{\gamma_0} P_{I,k} + 1 \right)^{-g} \end{aligned} \quad (12)$$

With the help of Eq. 9 and some manipulation, $F_{\gamma_b}(\gamma_{th})$ can be formulated as

$$\begin{aligned} F_{\gamma_{bi}}(\gamma_{th}) &= \Pr(\gamma_{bi} < \gamma_{th}) = \Pr \left(\frac{\gamma_{1,i} \gamma_{2,i}}{\gamma_{2,i} \gamma_{R_i} + C_i \gamma_{D_i}} < \gamma_{th} \right) \\ &= 1 - \int_0^\infty \exp \left(-\frac{\gamma_{th}}{\gamma_{1,i}} \gamma_{R_i} \right) f_{\gamma_{R_i}}(\gamma_{R_i}) d\gamma_{R_i} \\ &\quad \times \int_0^\infty \int_0^\infty \exp \left(-C_i \gamma_{th} \frac{\gamma_{D_i}}{\gamma_{1,i} \gamma_{2,i}} \right) f_{\gamma_{2,i}}(\gamma_{2,i}) f_{\gamma_{D_i}}(\gamma_{D_i}) d\gamma_{2,i} d\gamma_{D_i} \\ &= 1 - U_1 \times U_2 \end{aligned} \quad (13)$$

With the help of Eq. 9, Eq. 11 and the integral formula [10, Eq. (3.351.3)], U_1 can be formulated as

$$\begin{aligned} U_1 &= \int_0^\infty \exp \left(-\frac{\gamma_{th}}{\gamma_{1,i}} \gamma_{R_i} \right) f_{\gamma_{R_i}}(\gamma_{R_i}) d\gamma_{R_i} \\ &= \sum_{m=1}^{\rho(B)} \sum_{n=1}^{\tau_m(B)} \frac{\chi_{m,n}(B) P_{R_i,m}^{-n}}{(n-1)!} \int_0^\infty \frac{\gamma_{R_i}^{n-1}}{\exp \left[\gamma_{R_i} \left(\frac{\gamma_{th}}{\gamma_{1,i}} + \frac{1}{P_{R_i,m}} \right) \right]} d\gamma_{R_i} \\ &= \sum_{m=1}^{\rho(B)} \sum_{n=1}^{\tau_m(B)} \chi_{m,n}(B) \left(\frac{\gamma_{th}}{\gamma_{1,i}} P_{R_i,m} + 1 \right)^{-n} \end{aligned} \quad (14)$$

With the help of Eq. 9, Eq. 11 and the integral formula [10, Eq. (3.471.9)], U_2 can be formulated as

$$\begin{aligned}
 U_2 &= \int_0^\infty \int_0^\infty \exp\left(-C_i \gamma_{th} \frac{\gamma_{D_i}}{\bar{\gamma}_{1,i} \gamma_{2,i}}\right) f_{\gamma_{2,i}}(\gamma_{2,i}) f_{\gamma_{D_i}}(\gamma_{D_i}) d\gamma_{2,i} d\gamma_{D_i} \\
 &= \frac{1}{\bar{\gamma}_{2,i}} \int_0^\infty f_{\gamma_{D_i}}(\gamma_{D_i}) \int_0^\infty \exp\left(-C_i \gamma_{th} \frac{\gamma_{D_i}}{\bar{\gamma}_{1,i} \gamma_{2,i}} - \frac{\gamma_{2,i}}{\bar{\gamma}_{2,i}}\right) d\gamma_{2,i} \\
 &= \frac{2}{\bar{\gamma}_{2,i}} \int_0^\infty f_{\gamma_{D_i}}(\gamma_{D_i}) \sqrt{C_i \gamma_{th} \frac{\gamma_{D_i}}{\bar{\gamma}_{1,i}}} K_1\left(2 \sqrt{C_i \gamma_{th} \frac{\gamma_{D_i}}{\bar{\gamma}_{1,i} \gamma_{2,i}}}\right) d\gamma_{D_i}
 \end{aligned} \tag{15}$$

Where $K_n(x)$ is the n th-order modified Bessel function of the second kind [10, Eq. (3.471.9)]. Substituting Eq. 11 into Eq. 15, and after some algebraic manipulations, Eq. 15 can be calculated with the help of the integral formula [10, Eq. (6.631.3)], then it can obtained that

$$U_2 = \sum_{l=1}^{\rho(X)} \sum_{t=1}^{\tau_l(X)} \chi_{l,t}(X) (t!) \exp\left(\frac{C_i \gamma_{th} P_{D_i,l}}{4 \bar{\gamma}_{1,i} \bar{\gamma}_{2,i}}\right) W_{-t, \frac{1}{2}}\left(\frac{C_i \gamma_{th} P_{D_i,l}}{2 \bar{\gamma}_{1,i} \bar{\gamma}_{2,i}}\right) \tag{16}$$

Where $w_{\lambda, \mu}(\chi)$ is the Whittaker function defined in [10 Eq.(9.222.1)], Substituting Eq. 14 and Eq. 15 into Eq. 13, it can be obtained that

$$\begin{aligned}
 F_{\gamma_{th}}(\gamma_{th}) &= 1 - \sum_{m=1}^{\rho(B)} \sum_{n=1}^{\tau_m(B)} \chi_{m,n}(B) \left(\frac{\gamma_{th}}{\bar{\gamma}_1} P_{R_i,m} + 1\right)^{-n} \\
 &\quad \times \sum_{l=1}^{\rho(X)} \sum_{t=1}^{\tau_l(X)} \chi_{l,t}(X) (t!) \exp\left(\frac{C_i \gamma_{th} P_{D_i,l}}{4 \bar{\gamma}_{1,i} \bar{\gamma}_{2,i}}\right) W_{-t, \frac{1}{2}}\left(\frac{C_i \gamma_{th} P_{D_i,l}}{2 \bar{\gamma}_{1,i} \bar{\gamma}_{2,i}}\right)
 \end{aligned} \tag{17}$$

Then, Substituting Eq. 12 and Eq. 17 into Eq. 10, the outage probability of the AF cooperative diversity system with interferes can be given as Eq. 18

$$\begin{aligned}
 P_{out} &= \left[1 - \exp\left(-\frac{\gamma_{th}}{\bar{\gamma}_0}\right) \times \sum_{k=1}^{\rho(A)} \sum_{l=1}^{\tau_k(A)} \chi_{k,l}(A) \left(\frac{\gamma_{th}}{\bar{\gamma}_0} P_{I,k} + 1\right)^{-l}\right] \\
 &\quad \times \prod_{i=1}^L \left[1 - \sum_{m=1}^{\rho(B)} \sum_{n=1}^{\tau_m(B)} \chi_{m,n}(B) \left(\frac{\gamma_{th}}{\bar{\gamma}_{1,i}} P_{R_i,m} + 1\right)^{-n} \times \sum_{l=1}^{\rho(X)} \sum_{t=1}^{\tau_l(X)} \chi_{l,t}(X) (t!) \exp\left(\frac{C_i \gamma_{th} P_{D_i,l}}{4 \bar{\gamma}_{1,i} \bar{\gamma}_{2,i}}\right) W_{-t, \frac{1}{2}}\left(\frac{C_i \gamma_{th} P_{D_i,l}}{2 \bar{\gamma}_{1,i} \bar{\gamma}_{2,i}}\right)\right]
 \end{aligned} \tag{18}$$

In this paper, the relay and destination are subjected to the equal-power interferes, so according to paper [3]: $P_I = P_{I,k} \Omega_k / N_0$, $\forall k = 1, 2, \dots, N_I$, $P_{R_i} = P_{R_i,j} \Omega_j / N_0$, $\forall j = 1, 2, \dots, N_i$, $P_{D_i} = P_{D_i,l} \Omega_l / N_0$, $\forall l = 1, 2, \dots, M_i$

an $\rho(A) = \rho(B) = \rho(X) = 1$, $\tau_k(A) = N_I$, $\tau_m(B) = N_i$, $\tau_l(X) = M_i$, $\chi_{1,N_I}(A) = 1$, $\chi_{1,k}(A) = 0$, $k = 1, 2, \dots, N_I - 1$ and

the same as $\chi_{1,j}(B)$, $\chi_{1,l}(X)$, $\chi_{1,N_i}(B)$, $\chi_{1,M_i}(X)$. Therefore, Eq. 18 can be reduced to Eq. 19.

$$P_{out} = \left[1 - \exp\left(-\frac{\gamma_{th}}{\bar{\gamma}_0}\right) \times \left(\frac{\gamma_{th}}{\bar{\gamma}_0} P_I + 1\right)^{-N_I}\right] \times \prod_{i=1}^L \left[1 - \left(\frac{\gamma_{th}}{\bar{\gamma}_{1,i}} P_{R_i} + 1\right)^{-N_i} \times (M_i!) \exp\left(\frac{C_i \gamma_{th} P_{D_i}}{4 \bar{\gamma}_{1,i} \bar{\gamma}_{2,i}}\right) W_{-M_i, \frac{1}{2}}\left(\frac{C_i \gamma_{th} P_{D_i}}{2 \bar{\gamma}_{1,i} \bar{\gamma}_{2,i}}\right)\right] \tag{19}$$

In this section, we will present the simulation results to show the effect of interferes for the AF cooperative diversity system. For simulating, it is assumed that the SIR in indirect link is defined as $\beta_i = E[\gamma_{1,i}] / (E[\gamma_{R_i}] + E[\gamma_{D_i}])$, $i = 1, 2, \dots, L$, the signal-to-interference ratio (SIR) in direct link is defined as $\beta_0 = E[\gamma_0] / E[\gamma_I]$, and $10\bar{\gamma}_0 = \bar{\gamma}_{1,i} = \bar{\gamma}_{2,i} = \bar{\gamma}$, $\gamma_{th} = 5dB$, $E[\gamma_{R_i}] = E[\gamma_{D_i}]$. Fig. 1 shows the

outage performance as a function of the average $SNR(\bar{\gamma}_0)$ for different number of interferes, where we set $L=1$, $\beta_0 = \beta_i = 10dB$ for $i=1, \dots, L$, $N_I = N_i = M_i = N$. It shows that the outage performance appears worse when the number of interferes increased, and in the high SNR range the outage performance appears a floor effect for the impact of interferes. Fig. 2 shows the outage performance as a function of the average $SNR(\bar{\gamma}_0)$ for relay selection in this opportunity relaying system with interferes, where we set $N=10$, $L=1, 2, 3, 4$, $\beta_0 = \beta_i = 10dB$, $i=1, \dots, L$. It shows that the outage performance can be reduced effectively when the number of relay can be selected increases.

Figure 1. Outage probability as a function of the average $SNR(\bar{\gamma}_0)$ for different number of interferes.

Figure 2. Outage probability against $SNR(\bar{\gamma}_0)$ of relay selection in this opportunity relaying system with interferes.

Conclusions

In this paper, the outage probability performance of the opportunity relay AF cooperative system with multiple co-channel interferers at relays and destination is investigated. The closed expression of outage probability is derived. Through simulation, the result shows the outage performance will go to worse when the AF cooperative system is subjected to multiple interferers effect, but when this system increases the number of selected relays, the outage performance will be improved effectively.

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