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Outage Analysis and Power Allocation for Distributed Space-Time Coding-Based Cooperative Systems over Rayleigh Fading Channels

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Abstract

In this research, we study the outage probability for distributed space-time coding-based cooperative (DSTC) systems with amplify-and-forward relaying over Rayleigh fading channels with a high temporal correlation where the direct link between the source and the destination is available. In particular, we derive the upper and lower bounds of the outage probability as well as their corresponding asymptotic expressions. In addition, using only the average channel powers for the source-to-relay and relay-to-destination links, we propose an efficient power allocation scheme between the source and the relay to minimize the asymptotic upper bound of the outage probability. Through a numerical investigation, we verify the analytical expressions as well as the effectiveness of the proposed efficient power allocation. The numerical results show that the lower and upper bounds tightly correspond to the exact outage probability, and the proposed efficient power allocation scheme provides an outage probability similar to that of the optimal power allocation scheme that minimizes the exact outage probability.

Index Terms: Amplify-and-forward relay, Cooperative systems, Distributed space-time coding, Outage analysis, Power allocation

I. INTRODUCTION

Node cooperation techniques have attracted considerable attention from the perspective of achieving cooperative diversity. Distributed space-time coding [1] is a node cooperation technique, and distributed space-time coding-based cooperative (DSTC) systems have been well investigated in [2-6]. In [2], the bit error probability has been analyzed for DSTC systems using amplify-and-forward (AF) relaying, and the optimum power allocation for these systems has been presented assuming full instantaneous channel information at the source and the relay. In [3], the outage probability and the diversity–multiplexing tradeoff have been studied for DSTC systems using decode-and-forward relaying. In [4], adaptive buffer-aided DSTC schemes with AF relaying have been proposed, and their bit error probabilities have been investigated. In [5], assuming that instantaneous channel information is available at the relay, power allocation schemes have been proposed for DSTC systems with AF relaying in order to minimize the bit error probability and to maximize the data rate. In [6], using only the average channel power information, the authors have proposed power allocation for DSTC systems with AF relaying to minimize the outage probability, where the direct link between the source and the destination is ignored.

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In this paper, we focus on DSTC systems with AF relaying, where the Alamouti code [7, 8] is used for distributed space-time coding. Analogous to previous works, in DSTC systems, two transmission phases are considered as follows: in the first phase, both the relay and the destination receive the original data signals from the source, whereas in the second phase, only the destination receives the space-time coded signals from both the source and the relay.

In practice, a continuous wireless channel between the transmitter and the receiver may have a temporal correlation. Thus, considering highly correlated channels over time, we assume that the channel for the source-to-destination (S-D) link is constant during two phases.

In this study, we analyze the outage probability for DSTC systems with AF relaying over Rayleigh fading channels with a high temporal correlation, where the direct line between the source and the destination is assumed to be available unlike in the system model considered in [6]. However, unfortunately, it is expression for the exact outage probability. Thus, we derive the upper and lower bounds of the outage probability as well as their corresponding asymptotic expressions. Further, in previous works, instantaneous channel information was required for power allocation. However, assuming that only the average channel power for the source-to-relay (S-R) and relay-to-destination (R-D) links is known at the source and the relay, we propose a scheme for efficient power allocation between the source and the relay to minimize the asymptotic upper bound of the outage probability, and verify the effectiveness of this scheme. We do so by comparing the outage performances and the proposed and the optimal power allocation scheme that minimizes the exact outage probability.

II. SYSTEM MODEL

A. DSTC System Description

We consider a DSTC system consisting of three single-antenna nodes: a source, a relay, and a destination. As shown in Fig. 1, in the DSTC system, the source broadcasts signals to both the relay and the destination during the first time slot, and then, the relay and the source collaboratively transmit space-time coded signals to the destination over the second time slot. We assume perfect synchronization between the cooperative transmissions in the second time slot. After the destination receives the signals over the two time slots, it combines them using maximal ratio combining (MRC).

In this study, we focus on an AF relay, and thus, the space-time coded signals transmitted by the relay are generated from the noisy signals received from the source.

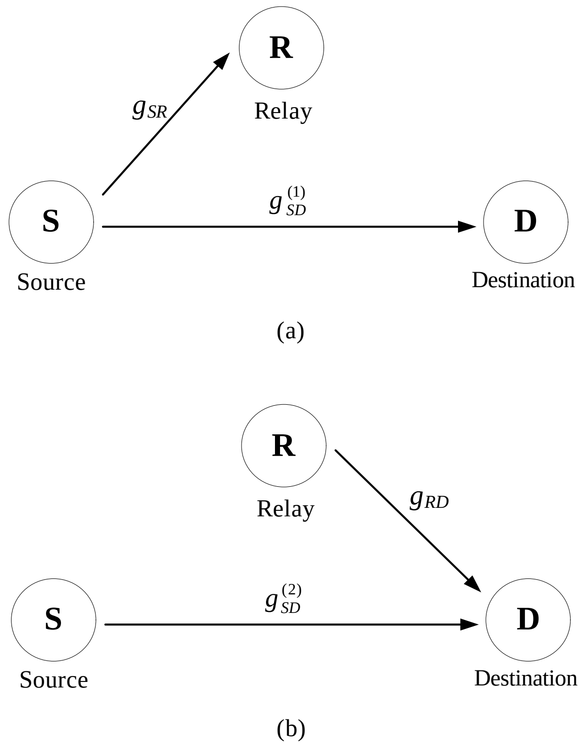

Fig. 1. Data transmissions in a distributed space-time coding-based cooperative system during (a) the first time slot and (b) the second time slot.

Further, the AF relay uses variable amplification for preventing the saturation of the relay amplifier and satisfying its transmit power constraint. We assume that the relay has the exact channel information for the S-R link, and the destination has the exact channel information for all the links, i.e., the S-D link, the S-R link, and the R-D link.

In the DSTC system, assuming that the channels are constant during a time slot, the complex channels for the S-D and S-R links in the first time slot are denoted by $g_{SD}^{(1)}$ and g_{SR}, respectively, and the complex channels for the S-D and R-D links in the second time slot are represented by $g_{SD}^{(2)}$ and g_{RD}, respectively. We assume that $g_{SD}^{(1)}$, g_{SR}, $g_{SD}^{(2)}$, and g_{RD} are complex Gaussian random variables with zero mean and ω_{SD}, ω_{SR}, ω_{SD}, and ω_{RD} variance, respectively. The random variables are independent of each other, but $g_{SD}^{(1)}$ and $g_{SD}^{(2)}$ can be dependent when the transmissions during the two successive time slots occur over the same frequency band. In particular, in low-mobility networks, the two consecutive channels for the S-D link are highly correlated. In order to focus on such a highly correlated case, in this study, we assume that $g_{SD}^{(1)} = g_{SD}^{(2)}$, which is represented by g_{SD}.

B. Signal-to-Noise Ratio for the DSTC System

Let $r_R^{(i,j)}$ and $r_D^{(i,j)}$ denote the received signals in the

j^{th} symbol duration in the i^{th} time slot at the relay and the destination, respectively, and $n_R^{(i,j)}$ and $n_D^{(i,j)}$ denote the additive complex white Gaussian noise with zero mean and σ^2 variance in the j^{th} symbol duration in the i^{th} time slot at the relay and the destination, respectively. Further, let $P_S^{(i)}$ denote the transmit power at the source in the i^{th} time slot, and P_R represent the transmit power at the relay.

During the first time slot, the source sequentially transmits two complex symbols s_1 and s_2, and the relay and the destination receive the two symbols over two symbol durations as follows:

$$r_R^{(1,i)} = g_{SR}\sqrt{P_S^{(1)}}\,s_i + n_R^{(1,i)}, \qquad (1)$$

$$r_D^{(1,i)} = g_{SD}\sqrt{P_S^{(1)}}\,s_i + n_D^{(1,i)}, \qquad (2)$$

for i = 1, 2, where $E[s_1 s_1^*] = E[s_2 s_2^*] = 1$. Then, the relay compensates for the phase of received signals by using the normalized weight $w_R = g_{SR}^* / |g_{SR}|$ for the DSTC transmission with the source, and amplifies them with the following variable amplification: $\alpha^2 = P_R / (|g_{SR}|^2 P_S^{(1)} + \sigma^2)$. During the second time slot, the relay transmits $\alpha w_R r_R^{(1,2)}$ and $-\alpha(w_R r_R^{(1,1)})^*$ during two symbol durations, and at the same time, the source transmits s_1 and s_2^*, respectively, where the Alamouti code is used for the DSTC transmission. Thus, the destination receives the DSTC signals as follows:

$$r_D^{(2,1)} = g_{SD}\sqrt{P_S^{(2)}}\,s_1 + g_{SD}\alpha w_R r_R^{(1,2)} + n_D^{(2,1)}, \qquad (3)$$

$$r_D^{(2,2)} = g_{SD}\sqrt{P_S^{(2)}}\,s_2^* - g_{RD}\alpha (w_R r_R^{(1,1)})^* + n_D^{(2,2)}. \qquad (4)$$

Then, at the destination, the received DSTC signals are decoupled as follows:

$$x_1 = g_{SD}^*\sqrt{P_S^{(2)}}\,r_D^{(2,1)} - \alpha |g_{SR}| g_{RD}\sqrt{P_S^{(1)}}\,r_D^{(2,2)*}, \qquad (5)$$

$$x_2 = \alpha |g_{SR}| g_{RD}^*\sqrt{P_S^{(1)}}\,r_D^{(2,1)} + g_{SD}\sqrt{P_S^{(2)}}\,r_D^{(2,2)*}. \qquad (6)$$

Finally, the destination combines the decoupled signals and the preceding received signals by using MRC as follows:

$$(|g_{RD}|^2 \alpha^2 + 1)^{-1} x_i + g_{SD}^* \sqrt{P_S^{(1)}}\,r_D^{(1,i)}, \qquad (7)$$

for i = 1, 2. The signal-to-noise ratio (SNR) of the MRC-combined signals is then obtained as follows:

$$\gamma = \frac{|g_{SD}|^2 P_S^{(2)} + |g_{RD}|^2 \alpha^2 |g_{SR}|^2 P_S^{(1)}}{|g_{RD}|^2 \alpha^2 \sigma^2 + \sigma^2} + \frac{|g_{SD}|^2 P_S^{(1)}}{\sigma^2}. \qquad (8)$$

Letting $z_{SD} = |g_{SD}|^2 P_S^{(2)} / \sigma^2$, $z_{SR} = |g_{SR}|^2 P_S^{(1)} / \sigma^2$, and $z_{RD} = |g_{RD}|^2 P_R / \sigma^2$, and inserting $\alpha^2 = P_R / (|g_{SR}|^2 P_S^{(1)} + \sigma^2)$ into (8), we can rewrite the MRC output SNR as follows:

$$\gamma = \frac{z_{SD} z_{SR} + z_{SR} z_{RD} + z_{SD}}{z_{SR} + z_{RD} + 1} + \eta z_{SD}, \qquad (9)$$

where $\eta = P_S^{(1)} / P_S^{(2)}$.

III. PERFORMANCE ANALYSIS

A. Lower and Upper Bounds on SNR

The MRC output SNR in (9) is upper bounded as follows:

$$\begin{aligned}
\gamma &= \frac{z_{SR} z_{RD} - z_{SD} z_{RD}}{z_{SR} + z_{RD} + 1} + (1+\eta) z_{SD} \\
&\le \begin{cases} \dfrac{z_{RD}(z_{SR} - z_{SD})}{z_{SR} + z_{RD} + 1} + (1+\eta) z_{SD} & \text{for } z_{SR} \le z_{SD} \\ \dfrac{z_{RD}(z_{SR} - z_{SD})}{z_{SR} + z_{RD} - z_{SD}} + (1+\eta) z_{SD} & \text{for } z_{SR} > z_{SD} \end{cases} \\
&\le \begin{cases} (1+\eta) z_{SD} & \text{for } z_{SR} \le z_{SD} \\ \min\{z_{RD} + (1+\eta) z_{SD}, z_{SR} + \eta z_{SD}\} & \text{for } z_{SR} > z_{SD} \end{cases} \\
&= \gamma^U.
\end{aligned} \qquad (10)$$

Further, a lower bound on the MRC output SNR is given as follows:

$$\gamma^L = \frac{z_{SR} z_{RD}}{z_{SR} + z_{RD} + 1} + \eta z_{SD}. \qquad (11)$$

B. Outage Probability Bounds

The outage probability is defined as the probability that the achievable data rate, $(1/2)\log_2(1+\gamma)$, falls below a specified outage threshold, R_{th}. Here, note that the achievable data rate decreases by half since two symbols are transmitted for four symbol durations. Then, by assuming that $\lambda_{th} = 2^{2R_{th}} - 1$, and using (10) and (11), we derive the lower and upper bounds on the outage probability for the DSTC system. The probability density functions (PDFs) of z_{SD}, z_{SR}, and z_{RD} are given in [9] as follows:

$$p_X(x) = \frac{1}{\beta_X} e^{-x/\beta_X} \quad \text{for} \quad X = z_{SD}, z_{SR}, z_{RD}, \qquad (12)$$

where $\beta_{z_{SD}} = \omega_{SD} P_S^{(2)} / \sigma^2$, $\beta_{z_{SR}} = \omega_{SR} P_S^{(1)} / \sigma^2$, and $\beta_{z_{RD}} = \omega_{RD} P_R / \sigma^2$. For brevity, let $\beta_{SD} = \beta_{z_{SD}}$, $\beta_{SR} = \beta_{z_{SR}}$, and $\beta_{RD} = \beta_{z_{RD}}$.

Using (10) and the PDFs in (12), we obtain a lower bound on the outage probability for the DSTC system as follows:

$$\begin{aligned}
&\Pr\{\gamma^U < \lambda_{th}\} = 1 - \Pr\{\gamma^U > \lambda_{th}\} \\
&= 1 - \Pr\{\min\{z_{RD} + (1+\eta)z_{SD}, z_{SR} + \eta z_{SD}\} > \lambda_{th}, z_{SR} > z_{SD}\} \\
&\quad - \Pr\{(1+\eta)z_{SD} > \lambda_{th}, z_{SR} < z_{SD}\} \\
&= 1 - \Pr\left\{z_{SD} > \frac{\lambda_{th}}{1+\eta}, z_{SR} > z_{SD}, z_{RD} > 0\right\} \\
&\quad - \Pr\left\{z_{SD} < \frac{\lambda_{th}}{1+\eta}, z_{SR} > \lambda_{th} - \eta z_{SD}, z_{RD} > \lambda_{th} - (1+\eta z_{SD})\right\} \\
&\quad - \Pr\left\{z_{SD} > \frac{\lambda_{th}}{1+\eta}, z_{SR} < \frac{\lambda_{th}}{1+\eta}\right\} - \Pr\left\{z_{SR} > \frac{\lambda_{th}}{1+\eta}, z_{SR} < z_{SD}\right\} \\
&= 1 - \frac{1}{\beta_{SD}} \int_{\frac{\lambda_{th}}{1+\eta}}^{\infty} e^{-z\left(\frac{1}{\beta_{SD}} + \frac{1}{\beta_{SR}}\right)} dz - \frac{1}{\beta_{SD}} e^{-\lambda_{th}\left(\frac{1}{\beta_{SR}} + \frac{1}{\beta_{RD}}\right)} \\
&\quad \times \int_0^{\frac{\lambda_{th}}{1+\eta}} e^{-z\left(\frac{1}{\beta_{SD}} - \frac{\eta}{\beta_{SR}} - \frac{1+\eta}{\beta_{RD}}\right)} dz \\
&\quad - e^{-\frac{\lambda_{th}}{(1+\eta)\beta_{SD}}}\left(1 - e^{-\frac{\lambda_{th}}{(1+\eta)\beta_{SR}}}\right) - \frac{1}{\beta_{SR}} \int_{\frac{\lambda_{th}}{1+\eta}}^{\infty} e^{-z\left(\frac{1}{\beta_{SD}} + \frac{1}{\beta_{SR}}\right)} dz \\
&= 1 - \left(\frac{\beta_{SR}\beta_{RD}}{\beta_{SR}\beta_{RD} - \eta\beta_{SD}\beta_{RD} - (1+\eta)\beta_{SD}\beta_{SR}}\right) \\
&\quad \times \left(e^{-\lambda_{th}\left(\frac{1}{\beta_{SR}} + \frac{1}{\beta_{RD}}\right)} - e^{-\frac{\lambda_{th}}{1+\eta}\left(\frac{1}{\beta_{SD}} + \frac{1}{\beta_{SR}}\right)}\right) - e^{-\frac{\lambda_{th}}{(1+\eta)\beta_{SD}}}.
\end{aligned} \quad (13)$$

For high transmit SNRs (i.e., $P_S^{(1)}/\sigma^2$, $P_S^{(2)}/\sigma^2$, and $P_R/\sigma^2 \to \infty$), the SNR lower bound in (11) can be approximated as follows:

$$\gamma^L \approx \min\{z_{SR}, z_{RD}\} + \eta z_{SD}. \quad (14)$$

Let $\gamma_{\min} = \min\{z_{SR}, z_{RD}\}$ and $y_{SD} = \eta z_{SD}$. Then, the cumulative distribution function of $\gamma_{\min}$ is given as follows:

$$F_{\gamma_{\min}} = 1 - \Pr\{z_{SR} > x\}\Pr\{z_{RD} > x\} = 1 - e^{-x\left(\frac{1}{\beta_{SR}} + \frac{1}{\beta_{RD}}\right)}. \quad (15)$$

Further, the PDF of y_{SD} is given as follows:

$$p_{y_{SD}}(x) = \frac{1}{\eta\beta_{SD}} e^{-x/(\eta\beta_{SD})}. \quad (16)$$

Using (14), $F_{\gamma_{\min}}(x)$, and $p_{y_{SD}}(x)$, we can approximate an upper bound on the outage probability of the DSTC system for high transmit SNRs as follows:

$$\begin{aligned}
&\Pr\{\gamma^L < \lambda_{th}\} \approx \Pr\{\gamma_{\min} + y_{SD} < \lambda_{th}\} \\
&= \int_0^{\lambda_{th}} F_{\gamma_{\min}}(\lambda_{th} - z) p_{y_{SD}}(z) dz \\
&= 1 - e^{-\frac{\lambda_{th}}{\eta\beta_{SD}}} + \frac{\beta_{SR}\beta_{RD}}{\beta_{SR}\beta_{RD} - \eta\beta_{SD}\beta_{RD} - \eta\beta_{SD}\beta_{SR}} \\
&\quad \times \left(e^{-\frac{\lambda_{th}}{\eta\beta_{SD}}} - e^{-\lambda_{th}\left(\frac{1}{\beta_{SR}} + \frac{1}{\beta_{RD}}\right)}\right).
\end{aligned} \quad (17)$$

C. Asymptotic Upper and Lower Bounds and Diversity Order

Let $P_S^{(1)} = P_S^{(2)} = \rho_1 P_t$, and $P_R = \rho_2 P_t$, where P_t denotes the total transmit power used for transmitting the two symbols in the DSTC system (i.e., $P_t = P_S^{(1)} + P_R + P_S^{(2)}$), $2\rho_1 + \rho_2 = 1$, and $\rho_1, \rho_2 > 0$. Note that $0 < \rho_1 < 0.5$ and $0 < \rho_2 < 1$.

When $P_t/\sigma^2 \to \infty$, by applying the approximation $e^a \approx 1 + a + a^2/2$ for $a \to 0$ to (13) and (17), we can obtain the asymptotic lower and upper bounds on the outage probability for the high transmit SNR regime, respectively, as follows:

$$\begin{aligned}
O^L = &\left(\frac{\lambda_{th}^2}{2\rho_1\omega_{SD}}\right)\left(\frac{P_t}{\sigma^2}\right)^{-2}\left[\left(\frac{1}{\rho_1\omega_{SR}} + \frac{2}{\rho_2\omega_{RD}} - \frac{1}{\rho_1\omega_{SD}}\right)^{-1}\right. \\
&\left. \times \left\{\left(\frac{1}{\rho_1\omega_{SR}} + \frac{1}{\rho_2\omega_{RD}}\right)^2 - \frac{1}{4}\left(\frac{1}{\rho_1\omega_{SD}} + \frac{1}{\rho_1\omega_{SR}}\right)^2\right\} - \frac{1}{4\rho_1\omega_{SD}}\right],
\end{aligned} \quad (18)$$

$$O^U = \frac{\lambda_{th}^2}{2\rho_1\omega_{SD}}\left(\frac{P_t}{\sigma^2}\right)^{-2}\left(\frac{1}{\rho_1\omega_{SR}} + \frac{1}{\rho_2\omega_{RD}}\right). \quad (19)$$

From (18) and (19), the diversity order for the DSTC system is obtained as follows:

$$-\lim_{P_t/\sigma^2 \to \infty} \frac{\log O}{\log(P_t/\sigma^2)} = 2, \quad (20)$$

where O represents the asymptotic outage probability bounds in (18) and (19), and implies that the diversity order for the DSTC system is 2.

IV. POWER ALLOCATION

In this section, assuming that only the average channel powers for the S-R and R-D links are known at the source and the relay, we propose an efficient power allocation scheme to improve the outage performance of the DSTC system. The efficient power allocation coefficients denoted by ρ_1^o and ρ_2^o for the source and the relay, respectively, are derived to minimize the upper bound of the outage probability in (19).

Inserting $\rho_2 = 1 - 2\rho_1$ into (19), we can rewrite the upper bound of the outage probability as follows:

$$O^U = \frac{\lambda_{th}^2}{2\rho_1\omega_{SD}}\left(\frac{P_t}{\sigma^2}\right)^{-2}\left(\frac{1}{\rho_1\omega_{SR}}+\frac{1}{(1-2\rho_1)\omega_{RD}}\right). \quad (21)$$

Taking the derivative of O^U in (21) with respect to ρ_1, we obtain the following:

$$\frac{dO^U}{d\rho_1} = \frac{\lambda_{th}^2}{2\rho_1\omega_{SD}}\left(\frac{P_t}{\sigma^2}\right)^{-2}\left[-\frac{1}{\rho_1^2\omega_{SR}}-\frac{1}{\rho_1(1-2\rho_1)\omega_{RD}} -\frac{1}{\rho_1^2\omega_{SR}}+\frac{2\omega_{RD}}{(\omega_{RD}-2\rho_1\omega_{RD})^2}\right]. \quad (22)$$

Using (22), we can derive the equation $dO^U/d\rho_1 = 0$ as follows:

$$(4\omega_{SR}-8\omega_{RD})\rho_1^2-(\omega_{SR}-8\omega_{RD})\rho_1-2\omega_{RD}=0. \quad (23)$$

From (23), ρ_1^o is finally obtained as follows:

$$\rho_1^o = \frac{\omega_{SR}-8\omega_{RD}+\sqrt{(\omega_{SR}-8\omega_{RD})^2+32(\omega_{SR}-2\omega_{RD})\omega_{RD}}}{8(\omega_{SR}-2\omega_{RD})}, \quad (24)$$

where $0<\rho_1^o<0.5$ since $2\rho_1+\rho_2=1$. Using (24), we also obtain $\rho_2^o = 1-2\rho_1^o$.

To show that ρ_1^o in (24) achieves the minimum O^U, we prove that $d^2O^U/d\rho_1^2>0$ as follows:

$$\begin{aligned}\frac{d^2O^U}{d\rho_1^2} &= \frac{\lambda_{th}^2}{2\rho_1^2\omega_{SD}}\left(\frac{P_t}{\sigma^2}\right)^{-2}\left[\frac{6}{\rho_1^2\omega_{SR}}+\frac{2-6\rho_1}{\rho_1(1-2\rho_1)^2\omega_{RD}} -\frac{2-12\rho_1}{(1-2\rho_1)^3\omega_{RD}}\right] \\ &= \frac{\lambda_{th}^2}{2\rho_1^2\omega_{SD}}\left(\frac{P_t}{\sigma^2}\right)^{-2}\left[\frac{6}{\rho_1^2\omega_{SR}}+\frac{\left(\sqrt{24}\rho_1-\sqrt{2}\right)^2+\left(8\sqrt{3}-12\right)\rho_1}{\rho_1(1-2\rho_1)^3\omega_{RD}}\right] \\ &>0.\end{aligned} \quad (25)$$

V. NUMERICAL RESULTS

In this section, we verify the analytical expressions for the lower and upper bounds on the outage probability in (13) and (17), respectively, as well as their corresponding asymptotic expressions in (18) and (19) by comparing with the simulation results of the exact outage probability. In addition, we verify the effectiveness of the proposed efficient power allocation scheme by comparing the simulation results of the exact outage probabilities for the optimal and the proposed power allocation schemes.

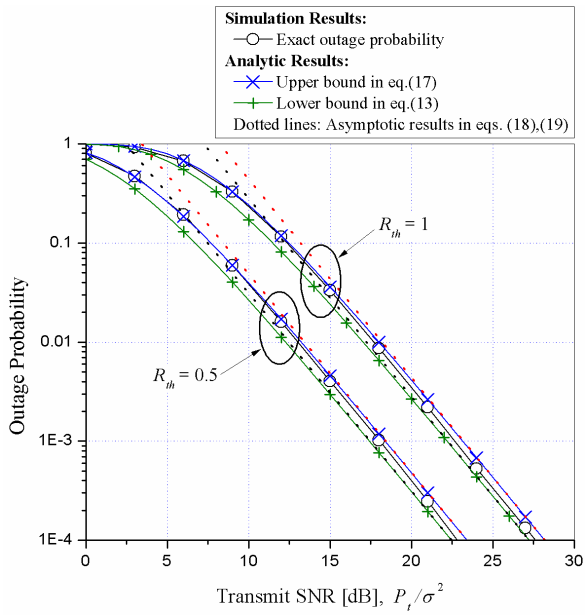

Fig. 2. Upper and lower bounds on the outage probability of the DSTC system and their asymptotic results when $\omega_{SD}=1$, $\omega_{SR}=2$, $\omega_{RD}=2$, and $\rho_1=0.3$.

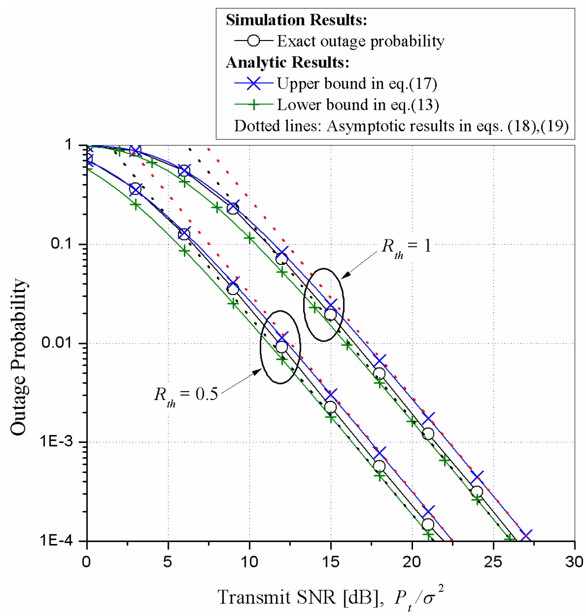

Fig. 3. Upper and lower bounds on the outage probability of the DSTC system and their asymptotic results when $\omega_{SD}=1$, $\omega_{SR}=5$, $\omega_{RD}=2$, and $\rho_1=0.3$.

Figs. 2 and 3 show the upper and lower bounds on the outage probability of the DSTC system as well as their asymptotic results for $\omega_{SR}=2$, $\omega_{RD}=2$ in Fig. 2 and $\omega_{SR}=5$, $\omega_{RD}=2$ in Fig. 3, when $\omega_{SD}=1$, $\rho_1=0.3$, and $R_{th}=0.5$, 1 bps/Hz. The analytical results of the

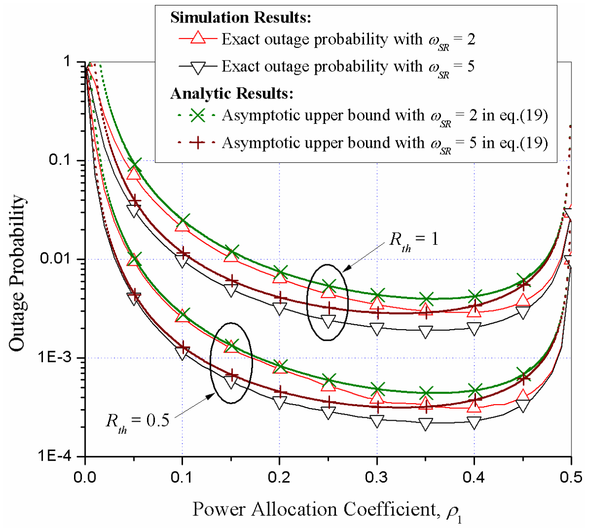

Fig. 4. Exact outage probability and the asymptotic upper bound on the outage probability for power allocation when $\omega_{SD} = 1$, $\omega_{RD} = 2$, and $P_t / \sigma^2 = 20$ dB.

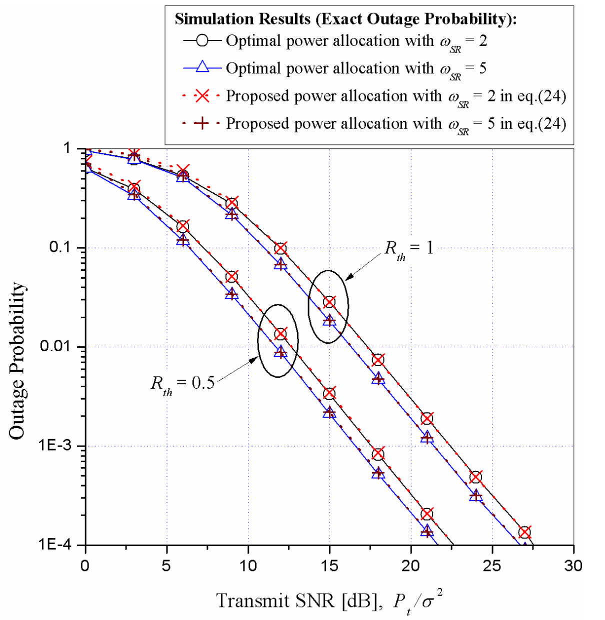

Fig. 5. Exact outage probabilities for the optimal and the proposed efficient power allocation schemes when $\omega_{SD} = 1$ and $\omega_{RD} = 2$.

lower and upper bounds are obtained using (13) and (17), respectively, and the corresponding asymptotic results are obtained using (18) and (19), respectively. From the figures, we observe that the lower and upper bounds tightly correspond with the exact outage probability for the different average channel powers and outage thresholds, even in the low transmit SNR regime. Further, the figures demonstrate that the asymptotic results perfectly match the results of their corresponding lower and upper bounds for a high transmit SNR.

Fig. 4 shows the exact outage probability and the asymptotic upper bound on the outage probability for power allocation between the source and the relay when $P_t / \sigma^2 = 20$ dB, $\omega_{SD} = 1$, $\omega_{RD} = 2$, ω_{SR} = 2, 5, and $R_{th} = 0.5$, 1 bps/Hz. The figure illustrates that a value of ρ_1 exists to minimize the outage probability. Further, the values of ρ_1 to minimize the asymptotic upper bound and the exact outage probability are slightly different, but their outage probabilities are almost the same.

Fig. 5 compares the exact outage probabilities for the optimal power allocation scheme and the proposed efficient power allocation scheme when $\omega_{SD} = 1, \omega_{RD} = 2$, ω_{SR} = 2, 5, and R_{th} = 0.5, 1 bps/Hz. The optimal power allocation scheme minimizes the exact outage probability with respect to $0 < \rho_1 < 0.5$, for which results are obtained through simulations. The figure demonstrates that the outage probability results of the proposed efficient power allocation obtained using (24) are extremely similar to those of the optimal power allocation for different average channel powers and outage thresholds.

VI. CONCLUSION

In this paper, we presented closed-form expressions for the lower and upper bounds on the outage probability for a DSTC system with AF relaying over Rayleigh fading channels with a high temporal correlation, which tightly correspond with the exact outage probability. Further, we provided the asymptotic expressions for the lower and upper bounds. In addition, a scheme for efficient power allocation using only the average channel powers for the source-to-relay and relay-to-destination links at the source and the relay is proposed to minimize the asymptotic upper bound of the outage probability. Numerical results show that the proposed efficient power allocation scheme achieves an outage performance similar to that of the optimal power allocation scheme.

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