Distributed Two-way Switch and Stay Combining with a Single Amplify-and-forward Relay

Lisheng Fan, Xianfu Lei, Rose Qingyang Hu, and Shengli Zhang

***Abstract*— This letter considers a two-phase two-way relay network (TWRN) consisting of two sources and a single amplify-and-forward (AF) relay. In order to efficiently exploit the direct link between sources for achieving full diversity order, we propose to utilize a distributed switch and stay combining (DSSC) in the two-phase TWRN. In DSSC, one branch out of the direct and relay branches is activated, and the branch switching occurs when the minimum end-to-end signal-to-noise ratio (SNR) of bi-directional communication falls below a preset threshold. We analyze the system performance over Rayleigh fading channels, by deriving the lower bounds and asymptotic expressions for the outage probability and symbol error rate (SER). It is shown that the DSSC preserves the same spectral efficiency as pure analogy network coding (ANC) protocol, while can concurrently achieve full diversity order as the optimal selection (OS) with less channel estimation complexity and lower switching rate. Numerical and simulation results demonstrate the proposed studies.**

***Index Terms*— Two-way relay network (TWRN), distributed switch and stay combining (DSSC), outage probability, symbol error rate (SER).**

I. Introduction

Wireless relaying has received much attention in the recent years, since it can improve the transmission capability and increase the coverage area [1]. Unlike the uni-directional relaying, two-way relaying can support the bi-directional data traffic through the same physical channels concurrently, which yields relatively high spectral efficiency. In a two-way relay network (TWRN), two source nodes exchange their messages with the help of one or more relays in between [2]. The system performances of TWRN such as outage probability and symbol error rate (SER) have been widely analyzed in the literature [3], [4].

For amplify-and-forward (AF) based relaying, there are two major protocols for TWRN: analog network coding (ANC) [4] and time-division broadcast (TDBC) [5] protocols. Specifically, ANC can achieve high spectral efficiency since it needs only two phases to complete the whole data communication. However, ANC cannot exploit the direct link between sources even if it physically exists due to the compact two-phase transmission and the half-duplex constraint. On the contrary, TDBC can efficiently exploit the direct link and achieve a higher diversity order, but it requires three phases and causes a considerable loss of spectral efficiency. By selecting a better branch out of the direct and relay branches, the optimal selection (OS) can be used to achieve the same diversity order as TDBC while preserve the high spectral efficiency as ANC concurrently. However, the OS technique needs to know the instantaneous channel parameters of both branches in every transmission block and may result in a high switching rate [6]–[8].

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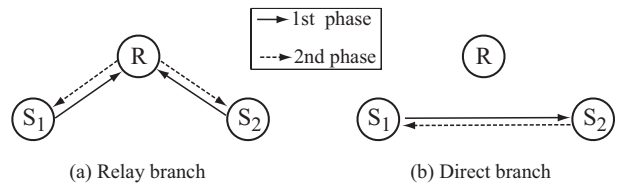

Fig. 1. Two-phase TWRN with DSSC

To reduce the implementation complexity of the OS technique, we here use a distributed switch and stay combining (DSSC)[1] [6] for a two-phase TWRN consisting of two sources and one AF relay, where the direct link between the sources exists. Only one branch out of the direct and relay branches is activated for each data transmission, and the branch switching occurs when the minimum end-to-end signal-to-noise ratio (SNR) of the bi-directional communication falls below a predetermined threshold. We analyze the system performance over Rayleigh fading channels. Specifically, we first derive a lower bound for the system outage probability and then provide an asymptotic expression for high SNR. We further preset a lower bound as well as an asymptotic expression for the system SER. From the analysis, we find that DSSC preserves the same high spectral efficiency as the pure ANC, while can concurrently achieve the full diversity order as the OS technique with less channel estimation complexity and lower switching rate.

II. System Model

Fig. 1 shows a two-phase TWRN with two sources S_i ($i = 1, 2$) and one AF relay R, where Fig. 1 (a) and (b) corresponds to the data communication through the relay and direct branch, respectively. All nodes in the network operate in a half-duplex mode, and all the channels are assumed reciprocal. The nodes are equipped with a single antenna due to the size limitation. In addition, we consider a moderate shadow environment, where the direct link between sources exists and can be used for improving the transmission reliability. To achieve the full diversity for the two-phase TWRN, the OS technique can be used to select a better branch out of the

[1]As in [6], the "distributed" here refers to that the two branches of the SSC are virtual, distributed.

$$P_{1,out}^{lb} = \begin{cases} G_1(\gamma_{th}) = p_R(1-e^{-\frac{\gamma_{th}\sigma^2}{P\varepsilon}})(1-e^{-\frac{T\sigma^2}{P\eta_{22}}}) + p_D(1-e^{-\frac{T\sigma^2}{P\varepsilon}})(1-e^{-\frac{\gamma_{th}\sigma^2}{P\eta_{12}}}) & \text{If } T \geq \gamma_{th} \\ G_1(\gamma_{th}) + p_R(e^{-\frac{T\sigma^2}{P\eta_{22}}} - e^{-\frac{2T\sigma^2}{P\alpha}-\frac{2\gamma_{th}\sigma^2}{P\beta}}) + p_D(e^{-\frac{T\sigma^2}{P\varepsilon}} - e^{-\frac{\gamma_{th}\sigma^2}{P\varepsilon}}) & \text{If } \frac{\gamma_{th}}{2} \leq T < \gamma_{th} \\ G_1(\gamma_{th}) + p_R(e^{-\frac{T\sigma^2}{P\eta_{22}}} - e^{-\frac{\gamma_{th}\sigma^2}{P\eta_{12}}}) + p_D(e^{-\frac{T\sigma^2}{P\varepsilon}} - e^{-\frac{\gamma_{th}\sigma^2}{P\varepsilon}}) & \text{If } T < \frac{\gamma_{th}}{2} \end{cases}. \quad (13)$$

$$P_{2,out}^{lb} = \begin{cases} G_2(\gamma_{th}) = p_R(1-e^{-\frac{\gamma_{th}\sigma^2}{P\varepsilon}})(1-e^{-\frac{T\sigma^2}{P\eta_{22}}}) + p_D(1-e^{-\frac{T\sigma^2}{P\varepsilon}})(1-e^{-\frac{\gamma_{th}\sigma^2}{P\eta_{21}}}) & \text{If } T \geq \gamma_{th} \\ G_2(\gamma_{th}) + p_R(e^{-\frac{T\sigma^2}{P\eta_{22}}} - e^{-\frac{2T\sigma^2}{P\beta}-\frac{2\gamma_{th}\sigma^2}{P\alpha}}) + p_D(e^{-\frac{T\sigma^2}{P\varepsilon}} - e^{-\frac{\gamma_{th}\sigma^2}{P\varepsilon}}) & \text{If } \frac{\gamma_{th}}{2} \leq T < \gamma_{th} \\ G_2(\gamma_{th}) + p_R(e^{-\frac{T\sigma^2}{P\eta_{22}}} - e^{-\frac{\gamma_{th}\sigma^2}{P\eta_{21}}}) + p_D(e^{-\frac{T\sigma^2}{P\varepsilon}} - e^{-\frac{\gamma_{th}\sigma^2}{P\varepsilon}}) & \text{If } T < \frac{\gamma_{th}}{2} \end{cases}. \quad (14)$$

direct and relay branches. However, this technique needs to know the instantaneous channel parameters of both branches in every transmission block and may result in a high switching rate [6]–[8]. To overcome these two drawbacks, we employ the technique of DSSC [6] for the considered system, where either relay or direct branch is activated for data communication, as shown in Fig. 1 (a) and (b), respectively.

When the relay branch is activated in Fig. 1 (a) [2], S_1 and S_2 send normalized signals x_1 and x_2 in the first phase, while R receives

$$y_r = h_{R,S_1}\sqrt{P}x_1 + h_{R,S_2}\sqrt{P}x_2 + n_r, \quad (1)$$

where $h_{R,S_1} \sim \mathcal{CN}(0,\alpha)$ and $h_{R,S_2} \sim \mathcal{CN}(0,\beta)$ denote the channel parameters of R-S_1 and R-S_2 links, respectively. α and β are the associated average channel gains. P is the transmit power of the nodes in the network, and $n_r \sim \mathcal{CN}(0,\sigma^2)$ is the additive noise at the relay. The relay R amplifies y_r by the factor $\kappa = \sqrt{\frac{P}{P|h_{R,S_1}|^2+P|h_{R,S_2}|^2+\sigma^2}}$, and then broadcasts the resultant signal to the two sources. S_i $(i=1,2)$ receives

$$y_i = h_{R,S_i}\kappa y_r + n_i \quad (2)$$

$$= h_{R,S_i}\kappa(h_{R,S_1}\sqrt{P}x_1 + h_{R,S_2}\sqrt{P}x_2 + n_r) + n_i, \quad (3)$$

where $n_i \sim \mathcal{CN}(0,\sigma^2)$ is the additive noise at source S_i. After canceling the self-interference term $\kappa h_{R,S_i}^2 x_i$ in (3), y_i becomes

$$y_i = \kappa h_{R,S_1}h_{R,S_2}\sqrt{P}x_j + \kappa h_{R,S_i}n_r + n_i, \quad (4)$$

where $j \in \{1,2\} \cap j \neq i$. From (4), the end-to-end SNRs of S_1 and S_2 are obtained as

$$\text{SNR}_1^R = \frac{P^2uv}{2Pu\sigma^2 + Pv\sigma^2 + \sigma^4}, \quad (5)$$

$$\text{SNR}_2^R = \frac{P^2uv}{Pu\sigma^2 + 2Pv\sigma^2 + \sigma^4}, \quad (6)$$

where $u \triangleq |h_{R,S_1}|^2$ and $v \triangleq |h_{R,S_2}|^2$ denote the channel gains of the R-S_1 and R-S_2 links, respectively.

On the other hand, when the direct branch is activated in Fig. 1 (b), two sources will take turn to send their information to each other. In this case, we can readily obtain the end-to-end SNRs as

$$\text{SNR}_1^D = \text{SNR}_2^D = Pw/\sigma^2, \quad (7)$$

with $w \triangleq |h_{S_1,S_2}|^2$ being the channel gain of the direct link, where $h_{S_1,S_2} \sim \mathcal{CN}(0,\varepsilon)$ and ε is the average channel gain.

[2]Pure ANC protocol will be applied if the relay branch is activated.

Mode of operation: At the beginning of each transmission slot, one branch needs to be activated. Specifically, suppose that the relay branch was used in the previous transmission slot, S_1 (or S_2)[3] compares $\min(\text{SNR}_1^R, \text{SNR}_2^R)$ with a preset SNR threshold T. The branch switching occurs when

$$\min(\text{SNR}_1^R, \text{SNR}_2^R) < T. \quad (8)$$

Otherwise, the relay branch continues to be used for data communication. Similarly, when the direct branch was activated in the previous transmission slot, the branch switching occurs when

$$\min(\text{SNR}_1^D, \text{SNR}_2^D) < T. \quad (9)$$

The switching process will be implemented by appropriate feedback [4] sent from S_1 (or S_2) to the other source S_2 (or S_1) and the relay, indicating a switching on the transmission path.

III. Performance Analysis

A. Closed-form lower bound of outage probability

Let $P_{i,out}$ denote the probability that the end-to-end SNR of S_i falls below an acceptable SNR threshold γ_{th}. Similar to [6, eq. (4)], we can express $P_{i,out}$ as

$$\begin{aligned} P_{i,out} &= p_R\text{Prob}[\text{SNR}_i^R < \gamma_{th}, \min(\text{SNR}_1^R, \text{SNR}_2^R) \geq T] \\ &+ p_R\text{Prob}[Pw/\sigma^2 < \gamma_{th}, \min(\text{SNR}_1^R, \text{SNR}_2^R) < T] \\ &+ p_D\text{Prob}[Pw/\sigma^2 < \gamma_{th}, Pw/\sigma^2 \geq T] \\ &+ p_D\text{Prob}[\text{SNR}_i^R < \gamma_{th}, Pw/\sigma^2 < T], \end{aligned} \quad (10)$$

where p_R and p_D denote the probability that the relay and the direct branches are used, respectively,

$$p_R = \frac{c_D}{c_R + c_D}, \quad p_D = \frac{c_R}{c_R + c_D}, \quad (11)$$

with $c_R = \text{Prob}[\min(\text{SNR}_1^R, \text{SNR}_2^R) < T]$ and $c_D = \text{Prob}[Pw/\sigma^2 < T]$.

It is hard to derive an exact expression for $P_{i,out}$, and hence we turn to use the upper bounds of SNR_1^R and SNR_2^R [10]

$$\text{SNR}_1^R < \frac{P}{\sigma^2}\min(u, \frac{v}{2}), \quad \text{SNR}_2^R < \frac{P}{\sigma^2}\min(\frac{u}{2}, v). \quad (12)$$

[3]Both S_1 and S_2 can be used to control the switching, since the channels are assumed reciprocal. Moreover, S_1 and S_2 can estimate the required channel parameters by themselves with the help of the pilots. The detail of channel estimation in two-way relay networks can be found in [9].

[4]As in [7], the feedback is not sent continuously, but only after a branch-switching decision.

$$P_{1,e}^{lb} = \frac{p_R}{2}\left(1-e^{-\frac{T\sigma^2}{P\eta_{22}}}\right)\left(1-\frac{1}{\sqrt{1+\frac{2\sigma^2}{\lambda P\varepsilon}}}\right) + \frac{p_D}{2}\left(1-e^{-\frac{T\sigma^2}{P\varepsilon}}\right)\left(1-\frac{1}{\sqrt{1+\frac{2\sigma^2}{\lambda P\eta_{12}}}}\right) + \left(\frac{p_R}{2}e^{-\frac{T\sigma^2}{P\eta_{22}}} + \frac{p_D}{2}e^{-\frac{T\sigma^2}{P\varepsilon}}\right)\text{erfc}\left(\sqrt{\frac{\lambda T}{2}}\right)$$
$$+ \frac{p_R}{2}e^{-\frac{2T\sigma^2}{P\alpha}}L\left(\frac{4\sigma^2}{\lambda P\beta}, \lambda T, \frac{\lambda T}{2}\right) + \frac{p_D}{2}L\left(\frac{2\sigma^2}{\lambda P\varepsilon}, \lambda T, \frac{\lambda T}{2}\right) - \frac{p_R}{2}L\left(\frac{2\sigma^2}{\lambda P\eta_{12}}, \lambda T\right) - \frac{p_D}{2}L\left(\frac{2\sigma^2}{\lambda P\varepsilon}, \lambda T\right). \quad (20)$$

$$P_{2,e}^{lb} = \frac{p_R}{2}\left(1-e^{-\frac{T\sigma^2}{P\eta_{22}}}\right)\left(1-\frac{1}{\sqrt{1+\frac{2\sigma^2}{\lambda P\varepsilon}}}\right) + \frac{p_D}{2}\left(1-e^{-\frac{T\sigma^2}{P\varepsilon}}\right)\left(1-\frac{1}{\sqrt{1+\frac{2\sigma^2}{\lambda P\eta_{21}}}}\right) + \left(\frac{p_R}{2}e^{-\frac{T\sigma^2}{P\eta_{22}}} + \frac{p_D}{2}e^{-\frac{T\sigma^2}{P\varepsilon}}\right)\text{erfc}\left(\sqrt{\frac{\lambda T}{2}}\right)$$
$$+ \frac{p_R}{2}e^{-\frac{2T\sigma^2}{P\beta}}L\left(\frac{4\sigma^2}{\lambda P\alpha}, \lambda T, \frac{\lambda T}{2}\right) + \frac{p_D}{2}L\left(\frac{2\sigma^2}{\lambda P\varepsilon}, \lambda T, \frac{\lambda T}{2}\right) - \frac{p_R}{2}L\left(\frac{2\sigma^2}{\lambda P\eta_{21}}, \lambda T\right) - \frac{p_D}{2}L\left(\frac{2\sigma^2}{\lambda P\varepsilon}, \lambda T\right). \quad (21)$$

Applying these two upper bounds into (10), and then considering that u, v and w follow exponential distribution with the mean of α, β and ε, respectively, we get the lower bound of $P_{i,out}$ shown in eqs. (13)-(14), where $\eta_{mn} = \alpha\beta/(n\alpha + m\beta)$, p_R and p_D are given by

$$p_R = \frac{1-e^{-\frac{T\sigma^2}{P\varepsilon}}}{2-e^{-\frac{T\sigma^2}{P\varepsilon}}-e^{-\frac{T\sigma^2}{P\eta_{22}}}}, p_D = \frac{1-e^{-\frac{T\sigma^2}{P\eta_{22}}}}{2-e^{-\frac{T\sigma^2}{P\varepsilon}}-e^{-\frac{T\sigma^2}{P\eta_{22}}}}. \quad (15)$$

We can then obtain a lower bound of the system outage probability as

$$P_{out}^{lb} = \frac{1}{2}(P_{1,out}^{lb} + P_{2,out}^{lb}). \quad (16)$$

B. Closed-form asymptotic outage probability

In order to obtain insights into the system performance, we further derive the asymptotic P_{out} with large transmit power P. Using the Taylor series expansion of $e^x \simeq 1 + x$ for small value of $|x|$ [11], we can obtain the asymptotic P_{out} with large transmit power P as

$$P_{out}^{asy} = \begin{cases} \frac{\zeta T\gamma_{th}\sigma^4}{P^2} & \text{If } T \geq \gamma_{th} \\ \frac{\zeta T\gamma_{th}\sigma^4}{P^2} + \frac{3(\gamma_{th}-T)\sigma^2}{2P(\varepsilon+\eta_{22})} & \text{If } \frac{\gamma_{th}}{2} \leq T < \gamma_{th} \\ \frac{\zeta T\gamma_{th}\sigma^4}{P^2} + \frac{(7\gamma_{th}-8T)\sigma^2}{4P(\varepsilon+\eta_{22})} & \text{If } T < \frac{\gamma_{th}}{2} \end{cases}, \quad (17)$$

where $\zeta = \frac{\varepsilon+\eta_{12}}{\varepsilon\eta_{12}(\varepsilon+\eta_{22})}$. From this asymptotic expression, we can find that for a given γ_{th}, the optimal switching threshold T^* of minimizing the outage probability is equal to γ_{th} [5]. We can find that the system full diversity can be achieved with order of two[6] when $T \geq \gamma_{th}$, as a large switching threshold makes the switch mechanism effective and the two branches can be efficiently used. On the other hand, the diversity order of the considered system gradually decreases to one with a smaller T in the region of $T < \gamma_{th}$. This is because that a small T makes the branch switching less likely happen so that diversity can not be efficiently exploited.

C. Closed-form lower bound of SER

Let $P_{i,e}$ denote the average symbol error rate at source S_i. For some linear modulation schemes [12], $P_{i,e}$ can be derived as

$$P_{i,e} = \int_0^\infty Q(\sqrt{\lambda\gamma_i})f_i(x)dx \quad (18)$$
$$= \frac{1}{\sqrt{2\pi}}\int_0^\infty F_i\left(\frac{x^2}{\lambda}\right)e^{-\frac{x^2}{2}}dx, \quad (19)$$

where partial integration technique is used from (18) to (19). Moreover, $Q(x)$ is the Gaussian-Q function [11], λ is the specific modulation constant, and $F_i(x)$ is the cumulative density function (CDF) of the end-to-end SNR γ_i at source S_i. From (13)-(14), we can obtain a lower bound of $F_i(x)$ after substituting γ_{th} by x. Then applying the lower bound of $F_i(x)$ into (19) and solving the required integral can yield the lower bound of $P_{i,e}$ shown in eqs. (20)-(21), where erfc(x) denotes the complementary error function [11] and

$$\begin{cases} L(y,z) = \frac{1}{\sqrt{1+y}}\text{erfc}\sqrt{(1+y)z} \\ L(y,z_1,z_2) = \frac{1}{\sqrt{1+y}}\left[\text{erfc}\sqrt{(1+y)z_1} - \text{erfc}\sqrt{(1+y)z_2}\right] \end{cases}. \quad (22)$$

The lower bound of the system average SER is computed as

$$P_e^{lb} = \frac{1}{2}(P_{1,e}^{lb} + P_{2,e}^{lb}). \quad (23)$$

D. Closed-form asymptotic SER

Applying the asymptotic P_{out} of (17) into (19) and solving the required integral, one can obtain an asymptotic expression for the system SER with a large transmit power P as

$$P_e^{asy} = \frac{\zeta T\sigma^4}{2\lambda P^2} + \frac{\rho\sigma^2}{P}, \quad (24)$$

with

$$\rho = \frac{\sqrt{\frac{T}{\lambda\pi}}\left(\frac{1}{\sqrt{2}}e^{-\frac{\lambda T}{2}} - e^{-\lambda T}\right) + \frac{1-\lambda T}{2\lambda}L\left(0, \frac{\lambda T}{2}, \lambda T\right)}{2(\varepsilon+\eta_{22})/3} + \frac{7\sqrt{\frac{T}{\lambda\pi}}e^{-\lambda T} + \frac{7-8\lambda T}{2\lambda}\text{erfc}(\sqrt{\lambda T})}{4(\varepsilon+\eta_{22})}. \quad (25)$$

[5] For $T \in [0, \gamma_{th})$, the first and third terms in (10), i.e., $p_R\text{Prob}[\text{SNR}_i^R < \gamma_{th}, \min(\text{SNR}_1^R, \text{SNR}_2^R) \geq T]$ and $p_D\text{Prob}[Pw/\sigma^2 < \gamma_{th}, Pw/\sigma^2 \geq T]$, will dominate the system diversity order that is equal to one. Hence, the optimal T is in the range $[\gamma_{th}, \infty]$. For $T \geq \gamma_{th}$, the exact outage probability expression $P_{i,out}$ in eq. (10) reduces to: $P_{i,out} = p_R\text{Prob}[Pw/\sigma^2 < \gamma_{th}, \min(\text{SNR}_1^R, \text{SNR}_2^R) < T] + p_D\text{Prob}[\text{SNR}_i^R < \gamma_{th}, Pw/\sigma^2 < T] = \frac{c_D c_R}{c_D + c_R}[\text{Prob}(Pw/\sigma^2 < \gamma_{th}) + \text{Prob}(\text{SNR}_i^R < \gamma_{th})]$. As both $c_D = \text{Prob}[Pw/\sigma^2 < T]$ and $c_R = \text{Prob}[\min(\text{SNR}_1^R, \text{SNR}_2^R) < T]$ increase with T, $\frac{c_D c_R}{c_D + c_R} = \frac{1}{\frac{1}{c_D} + \frac{1}{c_R}}$ also increases with T. Therefore, the optimal T for the exact outage expression is equal to γ_{th} as well.

[6] The diversity order is defined as $-\lim_{P->\infty} \log h(P)/\log P$, where $h(P)$ is the outage probability expression in this section and the SER expression in the next section, respectively.

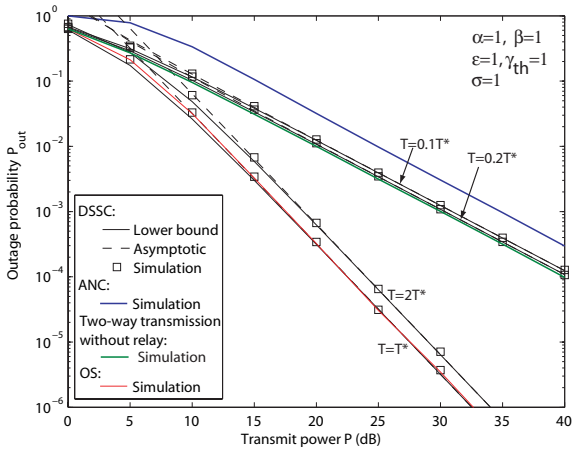

Fig. 2. Outage probability of two-phase TWRN versus the transmit power.

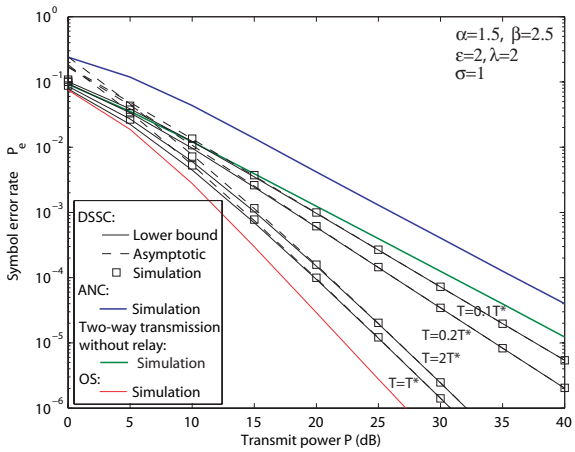

Fig. 3. SER of two-phase TWRN versus the transmit power.

As T becomes larger, it can be easily found that ρ approaches zero. Then, the first term in will dominate the system diversity order. Therefore, the system diversity order can approach two, which are also observed from the figure in the next section.

IV. Numerical and Simulation Results

To validate the proposed studies, we present some numerical and simulation results in this section. All links in the network are subject to Rayleigh fading. Without loss of generality, it is assumed that the additive noise has unit variance so that $\sigma = 1$. The binary phase shift keying (BPSK) modulation is applied with $\lambda = 2$.

Fig. 2 depicts the effect of transmit power on the outage probability of two-phase TWRN with $\alpha = \beta = \varepsilon = 1$, $\gamma_{th} = 1$ and $T \in \{0.1, 0.2, 1, 2\}T^*$, where T^* denotes the optimal switching threshold and it is equal to γ_{th}. For comparison, the outage performances of OS, ANC, and two-way transmission without relay[7] are also plotted. We can observe that for various values of T, the lower bound of the proposed DSSC is close to the exact value and the asymptotic result converges to the exact value when P is large. This verifies the derived lower bound and asymptotic expression for the outage probability of the proposed DSSC. Moreover, DSSC with $T = T^*$ can achieve the same performance as the optimal selection, and DSSC with $T \in \{1, 2\}T^*$ has the same curve slope as the OS technique. This indicates that the system full diversity is achieved when $T \geq T^*$. On the other hand, DSSC with $T \in \{0.1, 0.2\}T^*$ exhibits the same curve slope as fixed-branch transmission schemes such as ANC and two-way transmission without relay, because too small switching thresholds make the switching seldom happen.

Fig. 3 illustrates the SER of two-phase TWRN versus the transmit power with various values of switching threshold T, where $\alpha = 1.5, \beta = 2.5, \varepsilon = 2$. It can be easily verified from eq. (19) that $\frac{\partial^2 P_{i,out}^{lb}}{\partial^2 T} < 0$, $\frac{\partial^2 P_e^{lb}}{\partial^2 T} < 0$. Hence, the SER expression in (23) is a convex function with respect to T. The dichotomy method is used to efficiently find the optimal value of T. As observed from Fig. 3, DSSC with $T \in \{1, 2\}T^*$ provides the same diversity order as the OS technique. In addition, DSSC with $T \in \{0.1, 0.2\}T^*$ has the same diversity as fixed-branch transmission schemes.

In conclusion, we studied a DSSC scheme for a TWRN to utilize the direct link between two sources. We derived the tight lower bounds as well as asymptotic expressions for the outage probability and SER. It has been shown that DSSC has the ability to achieve the full diversity order as the OS technique with less implementation complexity.

[7] Two sources take turn to transmit signal to each other only through direct link.

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