Performance Analysis of Two-way Relay Selection Scheme Based on ARDT Protocol

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***Abstract*—Adaptive Relay-Assisted/ Direct Transmission (ARDT) proposed in [13] is a simple and efficient protocol which adaptively utilizes the direct link between two sources with only channel state information at receiver (CSIR), and it validly enhances the spectrum efficiency of time division broadcast (TDBC) system. In this paper, we combine ARDT with joint power allocation and relay selection for multi-relay scenario. Each relay optimize its own forwarding power to maximize the minimum end to end signal to noise ratio (SNR) towards two sources, and the optimal relay is then selected to cooperate. System outage probability, average throughput and average bit error rate (BER) are analyzed with theoretical upper and lower bounds. Numerical simulations validate the rationality of bounds, and show that whether maximal ratio combining (MRC) is adopted for receiving makes little difference. The proposed relay selection scheme is verified to outperform that based on original TDBC in reference work.**

***Index Terms*—ARDT, relay selection, power allocation, outage probability, average throughput,BER.**

I. Introduction

Two-way relaying is a promising wireless cooperation technique which achieves high spectrum efficiency [1]. Two sources may exchange their data in two time slots (2TS) or three time slots (3TS), which are known as multiple access broadcast (MABC) [2] and time division broadcast (TDBC) [3][4], respectively. TDBC is suboptimal in resource utilization since it requires more time slots; however, it allows two half-duplex sources to get additional space diversity from the direct link [2]. Besides, the relay can optimize the forwarding power for two signals received in the 1st and 2nd time slots without mutual interference [5].

In multi-relay networks, relay selection (RS) scheme determines the system performance [6]. In [7], a relay is chosen to minimize the average symbol error rate (SER) of the bidirectional amplify-and-forward (AF) networks. [8] replaced the RS criteria by maximizing sum rate. Two selection algorithms of maximizing the minimum instantaneous channel gain and maximizing sum channel gain, were introduced in [2] for MABC decode-and-forward (DF) bidirectional networks, and the very algorithms were discussed on outage probability for the asymmetric case in [9]. To further improve system performances, RS is combined with power allocation among sources and relays in some researches, where the authors considered max-min SNR as the optimization object in [10] and min-max SER in [11]. All mentioned researches above are under 2TS protocol. RS in 3TS is relatively less studied. [12] calculated the diversity gain for AF relay with three RS schemes: maximum average SNR, best worse channel, and maximum harmonic mean. [4] analyzed outage behavior with a max-min channel capacity RS method. However, these works did not consider relay power optimization in 3TS RS study, which is just the advantage of 3TS.

An improved TDBC protocol called adaptive relay-assisted/direct transmission (ARDT), was introduced in [13]. The basic idea is, two sources complete one transmission in 2 time slots without relay involved when direct link alone can support the communication requirement; otherwise, it turns to a cooperative transmission mode in which a relay node joins in and helps to forward as in traditional TDBC in the additional 3rd time slot (TS). It is proved that ARDT outperforms TDBC on system throughput at the cost of a negligible overhead. Motivated by this idea, we combine ARDT with joint power allocation and relay selection in multi-relay scenario which has only channel state information at receiver (CSIR). Each relay optimizes its forwarding power towards different sources to maximize the minimum end to end SNR, and the best relay is then chosen in a distributed way. The sources have two approaches to deal with received signals, either decoding the relay forwarded signal only or executing maximum ratio combining (MRC) for both direct and forwarded receiving. We analyze the system outage probability and average throughput for the two cases with effective upper and lower bounds. Numerical simulations validate the rationality of theoretical bounds and show that whether MRC is exploited by the sources makes little difference. It also confirms that the proposed scheme outperforms existing RS methods for TDBC protocol without adaptive transmission mode switching or relay power optimization.

II. System Model

The system consists of two source nodes S_1, S_2 which need to exchange data and a relay ensemble $\{R_k|k = 1,2,\cdots,K\}$. Rayleigh fading of channel S_1-S_2, S_1-R_k and S_2-R_k are denoted by $h_d, h_{1,k}, h_{2k}$: $h_d \sim \mathcal{CN}(0,\sigma_d^2), h_{ik} \sim \mathcal{CN}(0,\sigma_{ik}^2), i = 1,2$, and are supposed invariant during a bidirectional transmission. n_X^j denotes the Gaussian noise of j-th TS at node X, $j = 1,2,3; X \in \{S_1, S_2, R_k\}$, and their variances are N_0. Power constraint of sources and relay are P_{S_1}, P_{S_2}, P_R.

A. Signal Model with ARDT

According to the ARDT protocol [13], received signal at each TS is as follows: R_k, S_2 receive

$$y_{R_k}^{(1)} = h_{1k}\sqrt{P_{S_1}}x_1 + n_{R_k}^{(1)} \tag{1}$$
$$y_{S_2}^{(1)} = h_d\sqrt{P_{S_1}}x_1 + n_{S_2}^{(1)} \tag{2}$$

in the 1st TS; R_k, S_1 receive

$$y_{R_k}^{(2)} = h_{2k}\sqrt{P_{S_2}}x_2 + n_{R_k}^{(2)} \tag{3}$$
$$y_{S_1}^{(2)} = h_d\sqrt{P_{S_2}}x_2 + n_{S_1}^{(2)} \tag{4}$$

in the 2nd TS. In the 3rd TS (if it exists), all relays optimize their forwarding power towards two sources (see in Sec.B), and if R_k is chosen to help, it forwards

$$x_{R_k}^{(3)} = G_k\left(a_{1k}y_{R_k}^{(1)} + a_{2k}y_{R_k}^{(2)}\right) \tag{5}$$

where

$$G_k = \sqrt{\frac{P_R}{a_{1k}^2|h_{1k}|^2P_{S_1} + a_{2k}^2|h_{2k}|^2P_{S_2}}} \tag{6}$$

is the forwarding gain of R_k; a_{1k}, a_{2k} are the power allocation factors which satisfy $a_{1k}^2 + a_{2k}^2 = 1$. After self-interference cancellation at S_i, the effective received signal is

$$\begin{aligned} y_{S_i}^{(3)} = {} & G_k h_{1k}h_{2k}a_{jk}\sqrt{P_{S_j}}x_j + \\ & G_k h_{ik}\left(a_{1k}n_{R_k}^{(1)} + a_{2k}n_{R_k}^{(2)}\right) + n_{S_i}^{(3)} \end{aligned} \tag{7}$$

where $i \neq j$, $i, j \in \{1, 2\}$. Without loss of generality, assume all nodes have the same power constraint, *i.e.* $P_{S_1} = P_{S_2} = P_R \equiv P$, and notate $\rho = \frac{P}{N_0}$ as the transmission SNR, R_k-assisted received SNR expressions can be derived:

$$\gamma_{1k} = \frac{G_k^2|h_{1k}|^2|h_{2k}|^2\alpha_{2k}^2P}{\left(G_k^2|h_{1k}|^2+1\right)N_0} \approx \rho\frac{|h_{1k}|^2|h_{2k}|^2}{|h_{1k}|^2\lambda_{1k} + |h_{2k}|^2} \tag{8}$$

$$\gamma_{2k} = \frac{G_k^2|h_{1k}|^2|h_{2k}|^2\alpha_{1k}^2P}{\left(G_k^2|h_{2k}|^2+1\right)N_0} \approx \rho\frac{|h_{1k}|^2|h_{2k}|^2}{|h_{1k}|^2 + \lambda_{2k}|h_{2k}|^2} \tag{9}$$

where for simplification we denote

$$\lambda_{1k} = \frac{1+a_{1k}^2}{a_{2k}^2}, \quad \lambda_{2k} = \frac{1+a_{2k}^2}{a_{1k}^2} \tag{10}$$

B. Joint Power Allocation and Relay Selection

Selected relay shall maximize the minimal received SNR of two sources. On the other hand, received SNR is also determined by relay power allocation, thus the optimization problem is established

$$b = \arg\max_{k\in\{1,2,\cdots,K\}} \min\{\gamma_{1k}, \gamma_{2k}\} \tag{11}$$
$$s.t. \quad a_{1k}^2 + a_{2k}^2 = 1 \tag{12}$$

This principle of optimal selection considered both system throughput and fairness of two sources, and is widely accepted in theoretical researches [8][10]. Using the method of SNR balancing [6], the optimal performance of single relay R_k is achieved when $\gamma_{1k} = \gamma_{2k}$. From (8)(9) and (10), the optimal allocation factors for R_k are derived by

$$a_{1k}^2 = \frac{|h_{1k}|}{|h_{1k}| + |h_{2k}|}, \quad a_{2k}^2 = \frac{|h_{2k}|}{|h_{1k}| + |h_{2k}|} \tag{13}$$

and the corresponding received signal is

$$\gamma_{1k} = \gamma_{2k} = \rho\frac{|h_{1k}|^2|h_{2k}|^2}{\left(|h_{1k}| + |h_{2k}|\right)^2} \equiv \gamma_{R_k} \tag{14}$$

Thus the final relay selection strategy is

$$b = \arg\max_{k\in\{1,2,\cdots,K\}} \gamma_{R_k} \tag{15}$$

C. A Distributed Realization

Since ARDT only needs CSIR, it is suitable for the relay selection to be executed in a distributed manner. A back-off scheme from [14] may be adopted, where R_k may obtained the CSIR of h_{1k}, h_{2k} through pilot signal received in the 1st and 2nd TSs; each relay calculates its equivalent channel fading $\mu_k = \gamma_{R_k}/\rho$ independently, and set its own timer with value $\frac{T}{\mu_k}$, where T is a constant. Thus the optimal relay will expire its timer first and forward, which can be monitored by the rest ones and they are blocked and keep silent. It should be assumed that an arbitrary relay can hear of the others to avoid the hiding station effect.

III. Performance Analysis

System outage probability, average throughput and bit error rate (BER) are taken as performance metrics. According to ARDT, when $\log_2(1+\gamma_d) \geq r$, where $\gamma_d = \rho|h_d|^2$ is the received SNR of direct link, and r is the transmission rate of two sources, communication can be accomplished only through direct link, no outage event occurs, and system throughput is just r. Otherwise, relays are involved, and two decoding schemes of the sources can be considered:

- Decoding the signal of relay only (RO). Transmission succeeds when

$$\max_{k\in\{1,2,\cdots,K\}} \gamma_{R_k} \geq 2^{\frac{3}{2}r} - 1 \tag{16}$$

- Decoding the signal of direct transmission and relay forwarding with maximum ratio combining (MRC)

$$\gamma_d + \max_{k\in\{1,2,\cdots,K\}} \gamma_{R_k} \geq 2^{\frac{3}{2}r} - 1 \tag{17}$$

System throughput is $\frac{2}{3}r$ in this case. We use $\gamma_{\text{th1}} = 2^r - 1, \gamma_{\text{th2}} = 2^{\frac{3}{2}r} - 1$ for convenience.

Remark: $\gamma_{\text{th1}}, \gamma_{\text{th2}}$ can be understand in this way. It is reasonable for a single source to expect Bbits receiving on average in one TS of which the duration is T_s with bandwidth W. Thus in the direct transmission mode, a successful decoding means

$$W\log_2(1+\gamma_d)\cdot T_s \geq 2B \tag{18}$$

which corresponds to $\gamma_d \geq 2^{\frac{2B}{WT_s}} - 1$; in the relaying mode which last for three TSs, it is

$$W \log_2(1+\gamma_{R_b}) \cdot T_s \geq 3B \tag{19}$$

which corresponds to $\gamma_{R_b} \geq 2^{\frac{3B}{WT_s}} - 1$. By denoting $r = \frac{2B}{WT_s}$, we obtain the $\gamma_{\text{th1}}, \gamma_{\text{th2}}$ expressions above.

A. Outage Probability

1) RO Decoding: Outage Probability of RO is

$$\mathbf{P}_o^{\text{RO}} = \Pr\{\gamma_d < \gamma_{\text{th1}}\} \prod_{k=1}^{K} \Pr\{\gamma_{R_k} < \gamma_{\text{th2}}\} \tag{20}$$

where the distribution of γ_{R_k} is

$$\Pr\{\gamma_{R_k} < \gamma_{\text{th2}}\} = 1 - \int_0^{+\infty} \frac{2\left(y + \sqrt{\frac{\gamma_{\text{th2}}}{\rho}}\right)}{\sigma_{2k}^2} \times \exp\left\{ \frac{\left(y + \sqrt{\frac{\gamma_{\text{th2}}}{\rho}}\right)^2}{\sigma_{2k}^2} - \frac{\frac{\gamma_{\text{th2}}}{\rho}\left(y + \sqrt{\frac{\gamma_{\text{th2}}}{\rho}}\right)^2}{y^2\sigma_{1k}^2} \right\} \mathrm{d}y$$

The integration above is hard for exact calculation, and we turn to some effective lower and upper bounds:

$$\begin{aligned} \gamma_{R_k} &\geq \frac{\rho}{2}\frac{|h_{1k}|^2|h_{2k}|^2}{|h_{1k}|^2+|h_{2k}|^2} \equiv \gamma_{R_k}^{\text{LB}} && (21)\\ \gamma_{R_k} &\leq \rho\frac{|h_{1k}|^2|h_{2k}|^2}{|h_{1k}|^2+|h_{2k}|^2} \equiv \gamma_{R_k}^{\text{UB}} && (22) \end{aligned}$$

Thus the bounds of distribution can be determined

$$\begin{aligned} F_{\gamma_{R_k}^{\text{UB}}}(\gamma_{\text{th2}}) &= 1 - \exp\left\{-\frac{\gamma_{\text{th2}}}{\rho}\left(\frac{1}{\sigma_{1k}^2}+\frac{1}{\sigma_{2k}^2}\right)\right\} \\ &\quad \times \frac{2\gamma_{\text{th2}}}{\rho\sigma_{1k}\sigma_{2k}} K_1\left(\frac{2\gamma_{\text{th2}}}{\rho\sigma_{1k}\sigma_{2k}}\right) && (23) \end{aligned}$$

$$\begin{aligned} F_{\gamma_{R_k}^{\text{LB}}}(\gamma_{\text{th2}}) &= 1 - \exp\left\{-\frac{2\gamma_{\text{th2}}}{\rho}\left(\frac{1}{\sigma_{1k}^2}+\frac{1}{\sigma_{2k}^2}\right)\right\} \\ &\quad \times \frac{4\gamma_{\text{th2}}}{\rho\sigma_{1k}\sigma_{2k}} K_1\left(\frac{4\gamma_{\text{th2}}}{\rho\sigma_{1k}\sigma_{2k}}\right) && (24) \end{aligned}$$

and we have the outage bounds

$$\begin{aligned} \mathbf{P}_o^{\text{RO}} &\geq \left(1-\exp\left\{-\frac{\gamma_{\text{th1}}}{\rho\sigma_d^2}\right\}\right) \prod_{k=1}^{K} F_{\gamma_{R_k}^{\text{UB}}}(\gamma_{\text{th2}}) && (25)\\ \mathbf{P}_o^{\text{RO}} &\leq \left(1-\exp\left\{-\frac{\gamma_{\text{th1}}}{\rho\sigma_d^2}\right\}\right) \prod_{k=1}^{K} F_{\gamma_{R_k}^{\text{LB}}}(\gamma_{\text{th2}}) && (26) \end{aligned}$$

2) MRC Decoding: Outage probability of MRC is

$$\begin{aligned} \mathbf{P}_o^{\text{MRC}} &= \Pr\left\{\gamma_d < \gamma_{\text{th1}}, \gamma_d + \max_k \gamma_{R_k} < \gamma_{\text{th2}}\right\} \\ &= \int_0^{\frac{\gamma_{\text{th1}}}{\rho}} \frac{1}{\sigma_d^2} e^{-\frac{x}{\sigma_d^2}} \prod_{k=1}^{K} F_{\gamma_{R_k}}(\gamma_{\text{th2}} - \rho x)\,\mathrm{d}x && (27) \end{aligned}$$

The integration is also untractable, and we only focus on its asymptotic bounds. Using the 1st-order term of Taylor expansion of (23)(24), we have following approximation for the high SNR case:

$$\begin{aligned} F_{\gamma_{R_k}^{\text{UB}}}(\gamma_{\text{th2}}) &\approx \frac{\gamma_{\text{th2}}}{\rho}\left(\frac{1}{\sigma_{1k}^2}+\frac{1}{\sigma_{2k}^2}\right) && (28)\\ F_{\gamma_{R_k}^{\text{LB}}}(\gamma_{\text{th2}}) &\approx \frac{2\gamma_{\text{th2}}}{\rho}\left(\frac{1}{\sigma_{1k}^2}+\frac{1}{\sigma_{2k}^2}\right) && (29) \end{aligned}$$

substituting them into (27), the asymptotic bounds are derived:

$$\mathbf{P}_o^{\text{MRC}} \geq \frac{\gamma_{\text{th2}}^{K+1} - (\gamma_{\text{th2}} - \gamma_{\text{th1}})^{K+1}}{(K+1)\sigma_d^2\rho^{K+1}} \prod_{k=1}^{K}\left(\frac{1}{\sigma_{1k}^2}+\frac{1}{\sigma_{2k}^2}\right) \tag{30}$$

$$\mathbf{P}_o^{\text{MRC}} \leq \frac{\gamma_{\text{th2}}^{K+1} - (\gamma_{\text{th2}} - \gamma_{\text{th1}})^{K+1}}{(K+1)\sigma_d^2\rho^{K+1}} \prod_{k=1}^{K}\left(\frac{2}{\sigma_{1k}^2}+\frac{2}{\sigma_{2k}^2}\right) \tag{31}$$

Comparing the results of RO ((25)(26)) and MRC ((30)(31)), it is shown that both decoding scheme achieves (K+1)-order diversity, which is the full spatial diversity of system, and their performance only differ in coding gain.

B. Average Throughput

In original TDBC, system throughput is only $\frac{2}{3}r$ when source transmission rate is fixed r; that is lower than direct transmission or 2TS ANC scheme (of which the throughput is r). However, considered ARDT protocol may well overcome this shortage by adaptively switching between direct transmission and TDBC.

The system average throughput of RO and MRC are given by:

$$\begin{aligned} \bar{r}^{\text{RO}} &= r\Pr\{\gamma_d \geq \gamma_{\text{th1}}\} \\ &\quad + \frac{2r}{3}\Pr\left\{\gamma_d < \gamma_{\text{th1}}, \max_k \gamma_{R_k} \geq \gamma_{\text{th2}}\right\} \\ &= r\exp\left\{-\frac{\gamma_{\text{th1}}}{\rho\sigma_d^2}\right\} + \frac{2r}{3}\left(1-\exp\left\{-\frac{\gamma_{\text{th1}}}{\rho\sigma_d^2}\right\}\right) \\ &\quad \times \left[1 - \prod_{k=1}^{K} F_{\gamma_{R_k}}(\gamma_{\text{th2}})\right] && (32) \end{aligned}$$

$$\begin{aligned} \bar{r}^{\text{MRC}} &= r\Pr\{\gamma_d \geq \gamma_{\text{th1}}\} \\ &\quad + \frac{2r}{3}\Pr\left\{\gamma_d < \gamma_{\text{th1}}, \gamma_d + \max_k \gamma_{R_k} \geq \gamma_{\text{th2}}\right\} \\ &= r\exp\left\{-\frac{\gamma_{\text{th1}}}{\rho\sigma_d^2}\right\} + \frac{2r}{3}\int_0^{\frac{\gamma_{\text{th1}}}{\rho}} \frac{1}{\sigma_d^2}\exp\left\{-\frac{x}{\sigma_d^2}\right\} \\ &\quad \times \left[1 - \prod_{k=1}^{K} F_{\gamma_{R_k}}(\gamma_{\text{th2}} - \rho x)\right]\mathrm{d}x && (33) \end{aligned}$$

The two formulas above show that system throughput converges to r when $\rho \to +\infty$. Similar to the outage analysis, we may obtain the bounds for the throughput performance by substituting (23) and (24) into (32) (33), respectively.

C. Average Bit Error Rate

Average BER for a variety of modulation techniques is calculated by [15]

$$\mathbf{P}_b = \int_0^{+\infty} s \sum_{j=0}^{L-1} Q\left(\sqrt{t_j x}\right) f_\gamma(x)\,\mathrm{d}x \tag{34}$$

where $Q(\cdot)$ is Gaussian Q-function, $s = 1, L = 1, t_0 = 2$ for BPSK and $s = \frac{4}{\log_2 M}\left(1 - \frac{1}{\sqrt{M}}\right)$, $L = \frac{\sqrt{M}}{2}$, $t_j = \frac{3(1+2j)^2}{M-1}$ for M-QAM.

In original ARDT protocol [13], ideal coded transmission is required to guarantee the correctness when direct sending is chosen. Thus system error performance can not be investigated. However, we may extend it to weaker conditions of imperfect coding. To evaluate the modulation error rate, consider a weakest coding that only detects error (thus the receiving source is aware of error and asks for relay's help), the average BER of RO is derived

$$\begin{aligned}\mathbf{P}_b &= \Pr\{\text{error in direct mode}\} \times \Pr\{\text{error of relaying}\} \\ &= \int_0^{+\infty} s \sum_{j=0}^{L-1} Q\left(\sqrt{t_j x}\right) \mathrm{d}F_{\gamma_d}(x) \\ &\quad \times \int_0^{+\infty} s \sum_{j=0}^{L-1} Q\left(\sqrt{t_j x}\right) \mathrm{d}F_{\gamma_{R_b}}(x) \end{aligned} \tag{35}$$

where $F_{\gamma_{R_b}}(x)$ is bounded by (23)(24). After some manipulation, we shall give asymptotic solutions for BER with 1st-order term of Taylor expansion of the bounds (23)(24):

$$\begin{aligned}\mathbf{P}_b^{\text{RO}}|_{\text{lb,asym}} &= \frac{2^{K-2}\Gamma(K+\frac{1}{2})}{\Gamma(\frac{1}{2})\rho^{K+1}} s^2 \sum_{j=0}^{L} t_j^{-1} \sum_{j=0}^{L} t_j^{-K} \\ &\quad \times \frac{1}{\sigma_d^2} \prod_{k=1}^{K} \left(\frac{1}{\sigma_{1k}^2} + \frac{1}{\sigma_{2k}^2}\right) \end{aligned} \tag{36}$$

$$\begin{aligned}\mathbf{P}_b^{\text{RO}}|_{\text{ub,asym}} &= \frac{2^{2K-2}\Gamma(K+\frac{1}{2})}{\Gamma(\frac{1}{2})\rho^{K+1}} s^2 \sum_{j=0}^{L} t_j^{-1} \sum_{j=0}^{L} t_j^{-K} \\ &\quad \times \frac{1}{\sigma_d^2} \prod_{k=1}^{K} \left(\frac{1}{\sigma_{1k}^2} + \frac{1}{\sigma_{2k}^2}\right) \end{aligned} \tag{37}$$

IV. Numerical Results and Discussion

Monte Carlo simulations are carried out to verify the theoretical analysis comparing with the RS method proposed in [4], which selects best relay based on max-min channel capacity with equal forwarding power allocation and MRC in TDBC AF networks. Distance of S_1-S_2 is normalized, and relays locate along the perpendicular bisector of S_1-S_2. Pass loss of channel is assumed $\mathbf{E}[|h|^2] = (\alpha d)^{-n}$, and we suppose $\alpha = 2, n = 3$.

Fig.1 shows the system outage probability versus transmission SNR with different $K = 1, 3$ and target rate $r =$ 1bit/s/Hz. Simulation results are well bounded by the upper and lower bounds for both RO and MRC decoding, and they are shown to outperform referred RS scheme by about 2dB in transmission power. Besides, it shows little difference whether the receivers execute MRC, which is not surprising, since only when the direct channel suffers a deep fading the relay is to cooperate, leading to a small contribution of direct receiving.

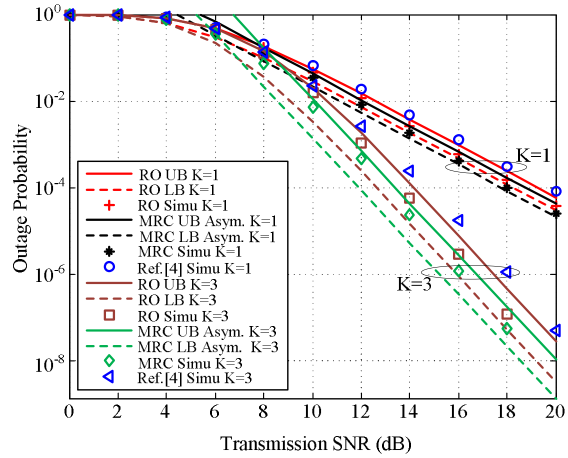

Fig. 1. Outage probability versus transmission SNR.

Relation between system average throughput and transmission SNR is exhibited in Fig.2 with $K = 3$, and only lower bounds are illustrated for clarity. It reveals that our scheme gains higher spectral efficiency than the referred one, and suffer little rate loss in high SNR regime as the average rate converges to the target r, because the direct link is utilized when SNR is sufficiently high and only 2 TSs for a transmission is needed; for the referred scheme, it is $\frac{\bar{r}_0}{r} \to \frac{2}{3}$ as a multiplexing cost for diversity. It also suggests the tiny difference between RO and MRC decoding.

From another point of view, the throughput versus target rate is shown in Fig.3. We have $\bar{r}_{\text{ref}} < \bar{r}_{\text{RO}} < \bar{r}_{\text{MRC}}$ in general, and RO and MRC performance are rather close, both of which are much higher than referred scheme, especially in small and large target rate regime. Meanwhile, in small target rate regime, say, $r <$ 1bit/s/Hz, throughput of all schemes seem to increase linearly with target rate, which may be explained by (32)(33), since $\frac{\gamma_{\text{th1}}}{\rho}$ is relatively small and the expression is dominated by the first term. However, the throughput reaches a peak and then falls rapidly with ascent of r, as outage occurs frequently due to the excessive requirement.

The final Fig.4 displays the BER performance of RO compared with referred scheme. BPSK is adopted for relay number $K = 1, 3$, respectively. The asymptotic bounds are still effective for both cases, and a $2 \sim 3$ dB power saving is obtained by the RO scheme, mainly thanks to the power optimization.

V. Conclusions

ARDT improves the system throughput of basic TDBC protocol with negligible overhead by adaptively switching between direct and relaying transmission. We combine ARDT with joint power allocation and relay selection scheme in

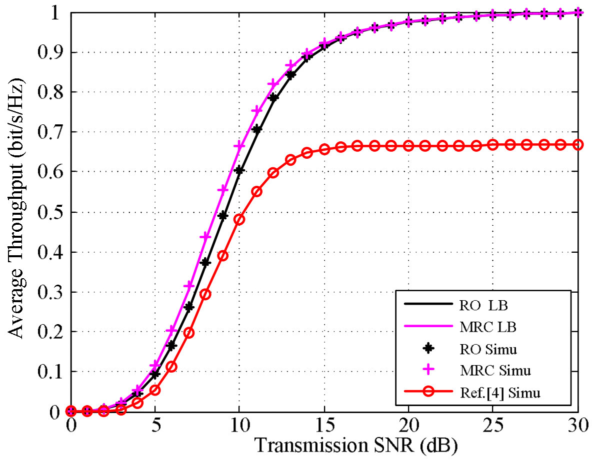

Fig. 2. System throughput versus transmission SNR.

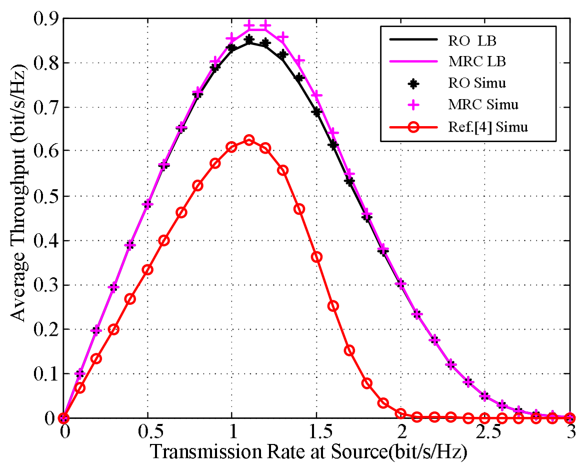

Fig. 3. System throughput versus transmission rate of sources.

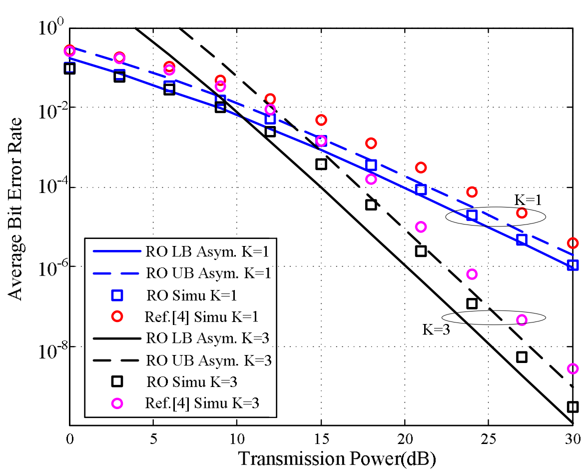

Fig. 4. Average BER versus transmission SNR with BPSK modulation.

a multi-relay scenario in this paper. All relays optimize its forwarding power toward two sources by maximizing the minimum of end to end SNR, then the best relay is chosen to cooperate in a distributed way. We calculate the upper and lower bounds for system outage probability, average throughput and average BER. Numerical simulations certify the rationality of the theoretical analysis. Compared with the basic TDBC-RS method proposed in [4], The proposed RS based on ARDT has obvious advantages on the performance metrics. Numerical results also show that whether MRC is operated by the receivers makes little difference on the outage and throughput behavior with the proposed RS.

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