STC-based Cooperative Relaying System with Adaptive Power Allocation [1]

Jingmei Zhang, Ying Wang, Ping Zhang

WTI Labs, Beijing University of Posts and Telecommunications, P.R. China
zhang_jingmei@sohu.com

Abstract. Cooperative relaying recently has emerged as a means of providing gains from spatial diversity to devices in a distributed manner. A cooperative relaying system deploying Alamouti's space-time coding (STC) design is investigated in this paper. According to amplify-and-forward (AF) and decode-and-forward (DF) modes, two TDMA-based cooperative transmission schemes are presented. Considering resource utilization efficiency, adaptive power allocation (PA) algorithms are proposed to adjust the power of each hop based on different channel conditions. Most importantly, the PA results also can be used to decide whether or not to relay, which recovers the loss of spectral efficiency due to the orthogonal transmission to a great extent. Numerical results indicate that the cooperative system with adaptive PA significantly outperforms the direct transmission system. Compared with the uniform power allocation (UPA), the proposed PA algorithm with power constraint of 1W can provide (52, 54)% capacity gains at most for Scheme (I, II), respectively.

1 Introduction

The next generation wireless systems are supposed to have an intense requirement for the very ambitious throughput and coverage, as well as the power and bandwidth efficiency. Transmission over wireless channels suffers from random fluctuations known as fading and from co-channel interference. Diversity is a powerful technique to mitigate fading and improve robustness to interference. Spatial diversity techniques are particularly attractive since they provide diversity gain without incurring an expenditure of transmission time or bandwidth. It has been indicated that Multiple-Input-Multiple-Output (MIMO) systems can combat the effects of fading in wireless system and provide better spatial diversity and higher system capacity [1][2].

In a different context, relaying is often regarded as a means of improving the performance of infrastructure-based networks by increasing their coverage [3]. However, the reduced end-to-end path loss comes at the cost of an inherent rate increase and the repetition-coded nature of relaying systems. Yet, relaying is a viable option for infrastructure-based networks, and it is a basic means for service provisioning in mobile ad-hoc networks. In addition, the integration of the cellular networks and the Wireless Local Area Networks (WLANs) has drawn considerable

[1] This paper is supported by NSFC (No. 60302024, 60496312).

attention from the research and commercial communities, which can both enhance the capacity of the cellular systems and extend the coverage area of 802.11 terminals [4].

Cooperative relaying brings together the worlds of MIMO and relaying systems. By allowing multiple users to cooperate and share their antennas effectively, virtual antenna arrays [5][6] can be built to realize spatial diversity gain in a distributed manner, which overcomes the size constraint of mobile terminal and some drawbacks of conventional relaying due to repetition coding. In [5][7], it is also shown that for channels with multiple relays, cooperative diversity with appropriately designed codes, such as space-time coding (STC), realizes full spatial diversity gain.

In this paper, the cooperative system adopting Alamouti's STC design is extended for a multi-antenna system based on multi-relay cooperation. Two TDMA-based cooperative transmission schemes are specialized for amplify-and-forward (AF) and decode-and-forward (DF) modes, respectively. Taking account of resource utilization efficiency, the adaptive power allocation (PA) algorithm, which usually remains to discuss or is replaced by the uniform power allocation (UPA) algorithm, is provided to enhance the system performance. The end-to-end achievable rate of the proposed system is investigated and compared to that of the conventional multi-antenna system.

2 System Model

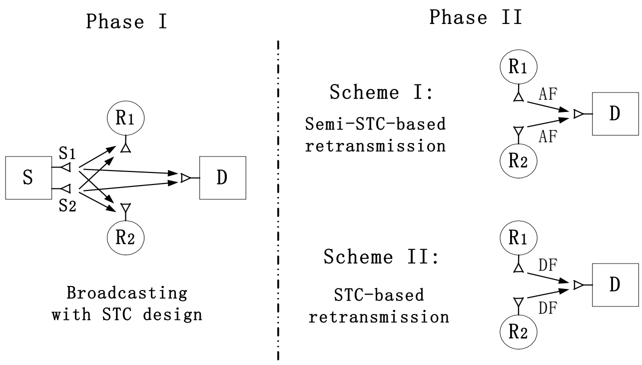


Fig. 1. Cooperative Relaying System and Two TDMA-based Transmission Schemes

The cooperative system analyzed in this paper is shown in Fig.1, which uses two relay terminals, R_1 and R_2, to relay the information transmitted by a source terminal S, to the destination terminal D. The terminal S is equipped with two antennas denoted by S_1 and S_2, and the other terminals are each with single antenna. Time division multiple access (TDMA) is adopted assuming a terminal cannot transmit and receive simultaneously. An Alamouti's STC design is employed in the source terminal S, and the relay terminal, R_j (j=1,2) assists in communication with the destination terminal D by either AF or DF mode. In the AF mode, R_j simply amplifies and retransmits the signal received from S, which is corrupted by fading and additive noise. In the DF mode, the signal received from S is demodulated and decoded before retransmission. In this paper, it is assumed that the transmissions suffer from the effects of frequency-flat fading, no channel knowledge in the transmitters, perfect channel state information in the receivers and perfect synchronization. Based on Alamouti's STC scheme, at a given symbol period, two symbols, x_1 and x_2, are simultaneously broadcasted by terminal S from its two antennas. The symbol transmitted from antenna S_1 is denoted by x_1 and from antenna S_2 by $(-x_2^*)$. During the next symbol period, symbol x_2 and x_1^* are transmitted from antenna S_1 and S_2 respectively, where * is the complex conjugate operation, and the symbol energy of x_1 and x_2 are both unit 1. Assuming the effects of the transmission attenuation and multi-path fading between the transmitter and the receiver are constant during two adjacent symbols, then during two consecutive symbols (t=1,2), the signals received by the terminal D, $y_{\mathrm{SD}}^{(t)}$, are

$$y_{\mathrm{SD}}^{(1)} = \sqrt{P_{\mathrm{S}}}\,(h_{\mathrm{S1D}} x_1 - h_{\mathrm{S2D}} x_2^*) + n_{\mathrm{SD}}^{(1)}\ ,\quad y_{\mathrm{SD}}^{(2)} = \sqrt{P_{\mathrm{S}}}\,(h_{\mathrm{S1D}} x_2 + h_{\mathrm{S2D}} x_1^*) + n_{\mathrm{SD}}^{(2)} \tag{1}$$

where P_{S} is the transmit power at antenna S_i (i=1,2), $h_{\mathrm{S}i\mathrm{D}}$ captures the path loss and multi-path fading between the source transmit antenna S_i and the destination terminal D, $n_{\mathrm{SD}}^{(t)}$ is the additive white noise, which is zero-mean, independent identical distributed (i.i.d.) Gaussian random variable with variance σ_{SD}^2. The Alamouti's receiver [1] is used at the destination terminal D to process the received signals, then, the following estimated symbols, $\tilde{x}_{1,\mathrm{SD}}$ and $\tilde{x}_{2,\mathrm{SD}}$, can be built for the direct link.

$$\tilde{x}_{1,\mathrm{SD}} = \sqrt{P_{\mathrm{S}}}\,(h_{\mathrm{S1D}}^* y_{\mathrm{SD}}^{(1)} + h_{\mathrm{S2D}} y_{\mathrm{SD}}^{(2)^*})\ ,\quad \tilde{x}_{2,\mathrm{SD}} = \sqrt{P_{\mathrm{S}}}\,(-h_{\mathrm{S2D}} y_{\mathrm{SD}}^{(1)^*} + h_{\mathrm{S1D}}^* y_{\mathrm{SD}}^{(2)}) \tag{2}$$

With transmission attenuation and fading realizations, $h_{\mathrm{S}i\mathrm{D}}$, the signal to noise ratio (SNR) of direct link can be expressed as [1]

$$\gamma_{\mathrm{SD}} = (\alpha_{\mathrm{S1D}} + \alpha_{\mathrm{S2D}}) P_{\mathrm{S}} \big/ \sigma_{\mathrm{SD}}^2 = \beta_0 P_{\mathrm{S}} \big/ \sigma_{\mathrm{SD}}^2 \tag{3}$$

where $\alpha_{\mathrm{S}i\mathrm{D}} = h_{\mathrm{S}i\mathrm{D}} h_{\mathrm{S}i\mathrm{D}}^*$ (i=1,2). Given W as the available bandwidth, the end-to-end achievable rate for direct transmission in terms of bps/Hz can be obtained as

$$C^{(\mathrm{D})} \big/ W = \log_2 (1 + \gamma_{\mathrm{SD}}) \tag{4}$$

Similarly, for the relay terminals, the signals received at R_j (j=1,2), $y_{\mathrm{SR}j}^{(t)}$, are

$$y_{\mathrm{SR}j}^{(1)} = \sqrt{P_{\mathrm{S}}}\,(h_{\mathrm{S1R}j} x_1 - h_{\mathrm{S2R}j} x_2^*) + n_{\mathrm{SR}j}^{(1)}\ ,\quad y_{\mathrm{SR}j}^{(2)} = \sqrt{P_{\mathrm{S}}}\,(h_{\mathrm{S1R}j} x_2 + h_{\mathrm{S2R}j} x_1^*) + n_{\mathrm{SR}j}^{(2)} \tag{5}$$

where $h_{\mathrm{S}i\mathrm{R}j}$ (i=1,2; j=1,2) captures the path loss and multi-path fading between S_i and R_j, $n_{\mathrm{SR}j}^{(t)}$ is a zero-mean, i.i.d. Gaussian random variable with variance $\sigma_{\mathrm{SR}j}^2$. After the signal from S is received at R_j, it is processed and forwarded to D by R_j with either AF or DF mode. According to different relaying methods, two cooperative schemes are introduced and the associated signal models are also discussed in Sec. 3.

3 Cooperative Schemes and Performance Analyses

Fig. 1 describes two TDMA-based cooperative schemes, which employ different types of processing by the relay terminals. The transmission consists of two phases. In phase I, S broadcasts information to R_1, R_2 and D with Alamouti's STC. In phase II, for Scheme I, S keeps silent, while R_1 and R_2 communicate with D simultaneously using AF mode. However, since in AF mode, the received signal, which is transmitted by STC design, is only amplified and repeated, this scheme can be regarded as semi-STC-based retransmission. Scheme II operates in similar fashion to Scheme I, except that R_1 and R_2 decode, re-encode, and retransmit using a suitable STC. This scheme can be considered as STC-based retransmission. For both schemes, the destination terminal D combines the signals received in the previous two phases.

3.1 Scheme I (AF mode)

In this scheme, the relay terminal R_j first normalizes the received signal, and then retransmits it to D with power P_{Rj}. This process can be regarded as amplifying signals with the amplification factor $G_{Rj}^2 = P_{Rj} \big/ [(\alpha_{S1Rj} + \alpha_{S2Rj})P_S + \sigma_{SRj}^2]$, where $\alpha_{SiRj} = h_{SiRj} h_{SiRj}^*$. Using (5), the signals $y_{RD}^{(t)}$ (t=1,2) received at D in phase II are

$$\begin{aligned} y_{RD}^{(1)} &= h_{R1D} G_{R1} y_{SR1}^{(1)} + h_{R2D} G_{R2} y_{SR2}^{(1)} + n_{RD}^{(1)} = H_1 x_1 - H_2 x_2^* + N_1 \\ y_{RD}^{(2)} &= h_{R1D} G_{R1} y_{SR1}^{(2)} + h_{R2D} G_{R2} y_{SR2}^{(2)} + n_{RD}^{(2)} = H_1 x_2 + H_2 x_1^* + N_2 \end{aligned} \qquad (6)$$

with

$$\begin{aligned} H_i &= \sqrt{P_S}\left(h_{SiR1} h_{R1D} G_{R1} + h_{SiR2} h_{R2D} G_{R2}\right) \\ N_t &= h_{R1D} G_{R1} n_{SR1}^{(t)} + h_{R2D} G_{R2} n_{SR2}^{(t)} + n_{RD}^{(t)} \end{aligned} \quad (i=1,2\ ;\ t=1,2) \qquad (7)$$

where h_{RjD} (j=1,2) captures the path loss and multi-path fading between R_j and D, $n_{RD}^{(t)}$ is a zero-mean, i.i.d. Gaussian random variable with variance σ_{RD}^2. The estimated symbols, $\tilde{x}_{1,RD}$ and $\tilde{x}_{2,RD}$, for the relaying link can be obtained as

$$\tilde{x}_{1,RD} = H_1^* y_{RD}^{(1)} + H_2 y_{RD}^{(2)*}, \quad \tilde{x}_{2,RD} = -H_2 y_{RD}^{(1)*} + H_1^* y_{RD}^{(2)} \qquad (8)$$

Assuming the noises at different receivers are uncorrelated, then $N_1 N_1^* = N_2 N_2^*$, and the SNR of the estimated signal in (8), $\gamma_{RD}^{(I)}$, can be written as

$$\gamma_{RD}^{(I)} = \frac{H_1 H_1^* + H_2 H_2^*}{N_1 N_1^*} = \frac{P_S(\beta_1 G_{R1}^2 + \beta_2 G_{R2}^2 + \beta_3 G_{R1} G_{R2})}{(\sigma_{RD}^2 + \alpha_{R1D} G_{R1}^2 \sigma_{SR1}^2 + \alpha_{R2D} G_{R2}^2 \sigma_{SR2}^2)} \qquad (9)$$

where

$$\begin{aligned} \beta_1 &= (\alpha_{S1R1} + \alpha_{S2R1})\alpha_{R1D}, \quad \beta_2 = (\alpha_{S1R2} + \alpha_{S2R2})\alpha_{R2D} \\ \beta_3 &= (h_{S1R1}^* h_{S1R2} + h_{S2R1}^* h_{S2R2}) h_{R1D}^* h_{R2D} + (h_{S1R1}^* h_{S1R2} + h_{S2R1}^* h_{S2R2})^* h_{R1D} h_{R2D}^* \end{aligned} \qquad (10)$$

Combines the signals received in two phases with the MRC receiver, the end-to-end achievable rate for Scheme I in terms of bps/Hz can be derived from (3) and (9) as

$$C^{(I)} \big/ W = \frac{1}{2}\left[\log_2\left(1 + \gamma_{SD} + \gamma_{RD}^{(I)}\right)\right] \qquad (11)$$

where the factor 1/2 accounts for the fact that information is conveyed to the destination terminal over two phases.

3.2 Scheme II (DF mode)

In this scheme, DF mode is adopted in phase II. Before forwarding, two relays detect the received signal with Alamouti's decoder [1]. According to (5), the estimated symbols, $\tilde{x}_{1,\mathrm{SR}}$ and $\tilde{x}_{2,\mathrm{SR}}$, for the 1st hop are as follows.

$$\begin{aligned} \tilde{x}_{1,\mathrm{SR}} &= h^*_{\mathrm{S1R1}} y^{(1)}_{\mathrm{SR1}} + h_{\mathrm{S2R1}} y^{(2)*}_{\mathrm{SR1}} + h^*_{\mathrm{S1R2}} y^{(1)}_{\mathrm{SR2}} + h_{\mathrm{S2R2}} y^{(2)*}_{\mathrm{SR2}} \\ \tilde{x}_{2,\mathrm{SR}} &= -h_{\mathrm{S2R1}} y^{(1)*}_{\mathrm{SR1}} + h^*_{\mathrm{S1R1}} y^{(2)}_{\mathrm{SR1}} - h_{\mathrm{S2R2}} y^{(1)*}_{\mathrm{SR2}} + h^*_{\mathrm{S1R2}} y^{(2)}_{\mathrm{SR2}} \end{aligned} \qquad \textbf{(12)}$$

With (5) and (12), the 1st-hop SNR for Scheme II can be written as

$$\gamma_{\mathrm{SR}} = \frac{(\alpha_{\mathrm{S1R1}} + \alpha_{\mathrm{S2R1}} + \alpha_{\mathrm{S1R2}} + \alpha_{\mathrm{S2R2}})^2 P_{\mathrm{S}}}{(\alpha_{\mathrm{S1R1}} + \alpha_{\mathrm{S2R1}})\sigma^2_{\mathrm{SR1}} + (\alpha_{\mathrm{S1R2}} + \alpha_{\mathrm{S2R2}})\sigma^2_{\mathrm{SR2}}} \qquad \textbf{(13)}$$

Assuming that the received signal is decoded correctly at the two relays, the estimated symbols, $\hat{x}_1$ and $\hat{x}_2$, are transmitted to D also with Alamouti's STC scheme. The transmit power at R_j is denoted as $P_{\mathrm{R}j}$. The symbol energy is unit 1. The destination terminal D receives signals from the two relays are

$$\begin{aligned} y^{(1)}_{\mathrm{RD}} &= h_{\mathrm{R1D}} \sqrt{P_{\mathrm{R1}}}\, \hat{x}_1 - h_{\mathrm{R2D}} \sqrt{P_{\mathrm{R2}}}\, \hat{x}^*_2 + n^{(1)}_{\mathrm{RD}} \\ y^{(2)}_{\mathrm{RD}} &= h_{\mathrm{R1D}} \sqrt{P_{\mathrm{R1}}}\, \hat{x}_2 + h_{\mathrm{R2D}} \sqrt{P_{\mathrm{R2}}}\, \hat{x}^*_1 + n^{(2)}_{\mathrm{RD}} \end{aligned} \qquad \textbf{(14)}$$

Also using Alamouti's combiner at the terminal D, the 2nd-hop SNR for Scheme II is

$$\gamma^{(\mathrm{II})}_{\mathrm{RD}} = (\alpha_{\mathrm{R1D}} P_{\mathrm{R1}} + \alpha_{\mathrm{R2D}} P_{\mathrm{R2}}) / \sigma^2_{\mathrm{RD}} \qquad \textbf{(15)}$$

Similarly, the destination D combines the signals received in the two phases with the MRC receiver. Requiring both the relays and destination to decode perfectly, the end-to-end achievable rate for Scheme II can be readily shown to be [5]

$$C^{(\mathrm{II})} / W = \frac{1}{2} \log_2 \left\{ \min\left[(1 + \gamma_{\mathrm{SR}}), \left(1 + \gamma_{\mathrm{SD}} + \gamma^{(\mathrm{II})}_{\mathrm{RD}}\right) \right] \right\} \qquad \textbf{(16)}$$

From (4), (11) and (16), it can be seen that the price to be paid for the relaying transmission over two phases is a reduction in spectral efficiency accounted for by the factor 1/2 in front of the log term.

4 Adaptive Power Allocation

Although the idea of deploying multi-antenna techniques through cooperation can enhance the system performance, the UPA algorithm, which allocates equal power to each hop in the network, does not utilize the system resources effectively [8][9]. So the adaptive PA algorithms, which adjust the power of each hop based on different channel conditions, are proposed in this section for different relaying schemes.

In order to provide a fair comparison, it is crucial that the total consumed energy of the cooperative relaying system does not exceed that of the corresponding direct system. In the conventional direct transmission system, the source terminal S transmits signals with total power $2P_S=P_0$ over a period T. Its consumed energy is P_0T. For the relaying transmission, the source terminal S first broadcasts information with power of $2P_S$ over a period of T/2. Assuming two relays transmit with equal power, i.e. $P_{R1}=P_{R2}=P_R$, the total power over the next T/2 is $2P_R$. Then the consumed energy in the relaying system is $2P_S$(T/2)+ $2P_R$(T/2). Thus, the consumed energy and total transmit power should be normalized as follows.

$$P_0 = P_S + P_R = P^{(I)} = P^{(II)} \tag{17}$$

where $P^{(I)}$ and $P^{(II)}$ are the power constraint for Scheme I and II, respectively. For the proposed system, the achievable rate can be regarded as a function of P_S and P_R. Therefore the object of the PA algorithm is to characterize these two parameters to maximize the achievable rate under a certain power constraint.

4.1 Adaptive PA for Scheme I

Taking the achievable rate as the optimization criterion, with (11), the PA issue for Scheme I can be described as

$$\begin{aligned} &\max_{P_S,P_R}\{C^{(I)}\} = \frac{1}{2}\max_{P_S,P_R}\left\{\log_2(1+\gamma_{SD}+\gamma_{RD}^{(I)})\right\} \\ &s.t.\ \ P_S + P_R = P^{(I)} \ \ (0 < P_S \le P^{(I)}\ ,\, 0 \le P_R < P^{(I)}) \end{aligned} \tag{18}$$

For simplicity, it is assumed that the noises at different receivers are with identical power σ_0^2. Using (3) and (9), after some elementary manipulations, (18) can be equivalent to maximize the function $F(P_S)$ with condition $0 < P_S \le P^{(I)}$, and

$$F\,(P_S) = \frac{P_S}{\sigma_0^2}\left[\beta_0 + \frac{\beta_1 f_2 + \beta_2 f_1 + \beta_3\sqrt{f_1 f_2}}{f_1 f_2 + (\alpha_{R_1D} f_2 + \alpha_{R_2D} f_1)(P^{(I)} - P_S)}(P^{(I)} - P_S)\right] \tag{19}$$

with

$$f_j = (\alpha_{S1Rj} + \alpha_{S2Rj})P_S + \sigma_0^2 \qquad (\,j{=}1,2\,) \tag{20}$$

Applying Lagrange Multiplier, P_S can be obtained through a polynomial after some elementary manipulations. The coefficients are very complicated and not presented here. Comparing the achievable rates, which are derived from the boundary point $P_S=P^{(I)}$ (means direct transmission) and other values of P_S obtained from the above method (means relaying transmission), $P_S^{(I)}$ which maximizes the data rate and satisfies $0 < P_S^{(I)} \le P^{(I)}$ can be chosen as the optimal solution, and accordingly, $P_R^{(I)} = P^{(I)} - P_S^{(I)}$.

4.2 Adaptive PA for Scheme II

For cooperative Scheme II, also taking the achievable rate as the optimization criterion, with (16) the PA issue for Scheme II can be described as

$$\begin{aligned} &\max_{P_S,P_R}\left\{C^{(II)}\right\} = \frac{1}{2}\max_{P_S,P_R}\left\{\log_2\left\{\min\left[\left(1+\gamma_{SR}\right),\left(1+\gamma_{SD}+\gamma_{RD}^{(II)}\right)\right]\right\}\right\} \\ &s.t.\;\; P_S + P_R = P^{(II)} \;\; (0 < P_S \le P^{(II)},\ 0 \le P_R < P^{(II)}) \end{aligned} \quad \textbf{(21)}$$

The possible solutions to such optimization issue have been discussed in [9]. Similarly, for (21) only when $\beta_{hop2} > \beta_0$, there may exist the optimal PA solution determined by $\gamma_{SR} = \gamma_{SD} + \gamma_{RD}^{(II)}$ for the relaying transmission, where $\beta_0 = \alpha_{S1D} + \alpha_{S2D}$ and $\beta_{hop2} = \alpha_{R1D} + \alpha_{R2D}$. Otherwise, $P_S = P^{(II)}$ is the final PA result, i.e. the direct transmission is favorable. Thus the optimal PA solution to Scheme II is

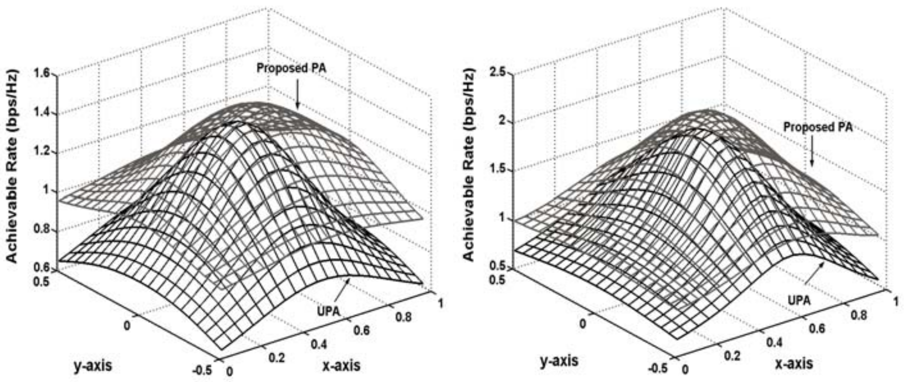
$$\begin{cases} P_S = \dfrac{\beta_{hop2} P^{(II)}}{\beta_{hop1} + \beta_{hop2} - \beta_0} \\ P_R = \dfrac{(\beta_{hop1} - \beta_0) P^{(II)}}{\beta_{hop1} + \beta_{hop2} - \beta_0} \end{cases} ; \quad \beta_{hop1} \ge \beta_0 \textit{ and } \beta_{hop2} > \beta_0 \quad \textbf{(22)}$$

where $\beta_{hop1} = \alpha_{S1R1} + \alpha_{S2R1} + \alpha_{S1R2} + \alpha_{S2R2}$. Note that in (22), the constraint $\beta_{hop1} \ge \beta_0$ comes from the power constraint $0 \le P_R < P^{(II)}$. From the above analyses, it can be concluded that if the conditions $\beta_{hop1} \ge \beta_0$ and $\beta_{hop2} > \beta_0$ are not satisfied, i.e. both channel conditions of the two hops are not better than that of the direct link, it may be beneficial to allocate all transmit power for direct communication rather than splitting power between the two hops.

Based on the discussions for the two schemes, it can be seen that the proposed PA algorithms not only can adjust the transmit power of each hop adaptively, but also can decide whether or not to relay grounded on the PA result, e.g. if $P_R=0$, it means that using the direct link only is superior to relay-assisted communication.

5 Numerical Results and Discussions

The performance of the cooperative system with two relaying transmission schemes and the efficacy of the proposed PA algorithms are assessed here with Monte Carlo simulation. The source terminal S and the destination terminal D are located at (0,0) and (1,0) respectively, and the two relays range from 0 to 1 along the x-axis and –0.5 to 0.5 along the y-axis. It is assumed that the two relays are spatially sufficiently close as to justify a common path loss; however, sufficiently far apart as to justify uncorrelated fading. Pass loss is given by d^{-4}, where d is the distance between the transmitter and receiver. The channel is assumed to obey the flat Rayleigh fading with an average power unity, and the noise power is normalized to unity.



(a) Scheme I (b) Scheme II

Fig. 2. Achievable Rate Comparison between UPA and Proposed PA Algorithm (P_0=1W)

Fig.2 shows the system achievable rate comparison between the UPA and the adaptive PA algorithm with P_0 =1W, where (a) is for Scheme I, and (b) for Scheme II. It shows that for both schemes, the system obtains the best performance when the relays are close to the midpoint between the source and destination terminals. As the distance with respect to that midpoint position increases, the performance degrades. Compared with the UPA, our proposed PA algorithm improves the achievable rate of the cooperative relaying system in the whole studied area.

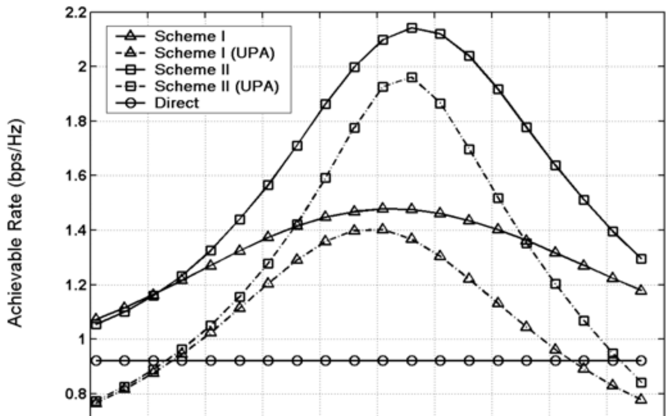


Fig. 3. Rate Comparison between Cooperative Relaying and Direct Transmission

In order to show the results more clearly, Fig.3 gives the rate comparison when the relays move along the line between S and D, where P_0 =1W. From Fig.3 it can be seen that with the proposed PA algorithm, the cooperative relaying transmission significantly outperforms the conventional direct transmission, especially with

Scheme II, since DF mode improves the performance in exchange of an increased complexity. However, for the UPA algorithm, when the relays are around the terminals S or D, the relaying transmission is even inferior to the direct transmission since UPA cannot switch the relaying to the direct transmission adaptively as the proposed PA algorithm. Compared with UPA, for Scheme I, the adaptive PA can provide the gains of (40, 52)% for the cases when the relays are around S and D, respectively. For Scheme II, the gains are (36, 54)% correspondingly. When the relays are around the midpoint of the terminals S and D, the gains decrease to (5, 9)% for Scheme (I, II), respectively on account of the similar PA solutions caused by the parallelism of the two-hop channel conditions.

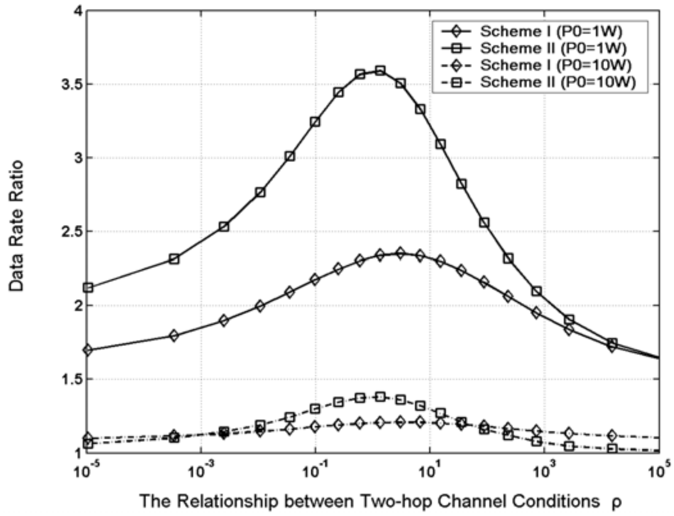


Fig. 4. Impact of the two-hop channel conditions on the performance of relaying system

Fig.4 depicts the data rate ratio of the relaying transmission to the direct transmission as a function of ρ, where $\rho = \beta_{\text{hop1}} / \beta_{\text{hop2}}$ represents the relationship between the two-hop channel conditions. The adaptive PA algorithm is adopted. For P_0=1W, it can be observed that the performance gain provided by the cooperative relaying is significant when $\rho \approx 1$, and if $\rho >> 1$ or $\rho << 1$, i.e. the two hops are badly unbalanced, the gain decreases, especially for Scheme II. Scheme I is less sensitive to ρ, since the AF mode responds gracefully to the channel condition on any individual link between two terminals, while the DF mode introduces decoding error if any hop produces error. On the other hand, it can be seen from (11) that there is not much immediate influence of ρ on the performance of Scheme I, which is different from Scheme II (see (16)). At high power constraint (P_0=10W), the advantage of relaying transmission weakens since the cooperative diversity may not recover fully from the loss in spectral efficiency due to transmission over two phases. If it were not for the adaptive PA algorithm, direct communication would be even more attractive somewhere, which is testified in Fig.3 when UPA is used. In addition, it also can be seen that for high power, when $\rho >> 1$ or $\rho << 1$, Scheme I outperforms Scheme II since the latter may be limited with the deteriorated quality of channel at the worse hop which may becomes a bottleneck.

6 Conclusions

A cooperative relaying system is studied in this paper, where Alamouti's STC design is extended for a multi-antenna environment based on multi-relay cooperation. According to different relaying methods, AF or DF mode, two TDMA-based cooperative transmission schemes are presented and their performances are also analyzed. Considering the resource utilization efficiency, the adaptive PA algorithms are proposed to adjust the power of each hop with the achievable rate as the optimization criterion. Most importantly, the proposed PA algorithms can adaptively switch relaying to direct transmission based on PA results, which recovers the loss of spectral efficiency due to the orthogonal transmission to a great extent. The numerical results indicate that with low power constraint (P_0=1W), the cooperative system with adaptive PA algorithm significantly outperforms the direct transmission system, whose achievable rate can be improved to 2~3 times than before averagely by Scheme I and II respectively. With high power (P_0=10W), the superiority of the relaying transmission weakens, however, there are still performance gains if the adaptive PA algorithm is utilized. It can be concluded that with efficient PA algorithm and appropriate relaying selection criterion, the idea of applying cooperative schemes into effective point-to-point relaying channels can be easily extended to larger networks and more complex transmission environments.

References

[1] S. M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications", *IEEE Journal on selected areas in communications*, Vol. 16, No. 8, Oct. 1998.

[2] E. Telatar, "Capacity of Multi-antenna Gaussian Channels," AT&T Bell Laboratories, Tech. Memo. June 1995.

[3] Pabst R., Walke B. H. and et al., "Relay-based Deployment Concepts for Wireless and Mobile Broadband Radio," *IEEE Communications Magazine*, vol. 42, pp. 80-89, Sept. 2004.

[4] Hung-yu Wei, and Richard D. Gitlin, "WWAN/WLAN Two-Hop-Relay Architecture for Capacity Enhancement," *IEEE Wireless Communications and Networking Conference (WCNC 04')*, March 2004.

[5] J. Nicholas Laneman, "Cooperative Diversity in Wireless Networks: Algorithms and Architectures," M.I.T. Doctoral Dissertation, Sep. 2002.

[6] Mischa Dohler, E. Lefranc, H. Aghvami, "Virtual Antenna Arrays for Future Wireless Mobile Communication Systems", *IEEE ICT 2002*, Beijing, China, 2002.

[7] R. U. Nabar and H. Bolcskei, "Space-time Signal Design for Fading Relay Channels," in *Proc. IEEE GLOBECOM*, San Francisco, CA, Dec. 2003.

[8] Zhang Jingmei, Zhang Qi, et. al, "Adaptive Optimal Transmit Power Allocation for Two-hop Non-regenerative Wireless Relaying System", *IEEE VTC'04 Spring*, 2004.

[9] Zhang Qi, Zhang Jingmei, et al. "Power Allocation for Regenerative Relay Channel with Rayleigh Fading", *IEEE VTC'04 Spring*, 2004.