Efficient Power Allocation Schemes for MIMO Cooperative Relaying Systems

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Abstract–**Cooperative relaying technology is proved to be an efficient method to exploit the capacity of the multiple-input multiple-output (MIMO) wireless system. In this paper, the transmit power allocation (TPA) strategies for various relaying protocols are investigated for MIMO cooperative relaying systems. First, the TPA scheme for compress-and-forward (CF) protocol is proposed with closed-form by utilizing the Lagrange function. Second, a novel best node and antenna selection strategy is exploited for decode-and-forward (DF) relaying, which can improve the efficiency for the transmit power. Besides, the TPA scheme for amplify-and-forward (AF) protocol is analyzed. Simulation results show that the efficient TPA schemes can achieve significant gain by exploit the features of multihop transmission. Furthermore, compared with AF, DF, and hybrid decode-and-forward (HDF) protocols, the CF relaying can be used for coverage extension, which is a candidate technology for future LTE-A networks.**

Keywords- cooperative relay, MIMO relaying, compress-and-forward, decode-and-forward, coverage extension

I. INTRODUCTION

As a promising technology for B3G/4G wireless communications systems, multiple-input and multiple-output (MIMO) technique is well studied to provide significant improvements in terms of capacity, spectral efficiency and link reliability [1]. Furthermore, the relay technology is widely discussed and proposed for different scenarios for future implementations, such as fixed relays or nomadic relays for capacity gain and coverage extension in IEEE 802.16j [2]. Therefore, combined with the two techniques, the MIMO cooperative relaying system attracts much attention recently, and the corresponding relay-enabled standards has been discussed and proposed in LTE-A systems [3].

In relay systems, there are a total of four types of relaying protocols. As the traditional methods, the amplify-and-forward (AF) and decode-and-forward (DF) relaying methods are well studied. In AF system, the relay node (RN) only amplifies the signal and then forward to the destination without any additional disposal. It is the easiest relaying mode, which is available to implement but can not achieve optimal performance gain. The DF relaying protocol can obtain high performance gain due to decode the received signals in RN, and transmit the re-coding signals to the destination; however, the complexity of DF mode is relatively high. Therefore, two new relaying modes are emerged, hybrid decode-and-forward (HDF) and compress-and-forward (CF). In HDF relaying system, the RN uses filter matrix to reduce the interferences between the different data streams. And in CF relaying system, the RN compresses (also means quantizes) the received signal from transmitter (TX), and then forward to receiver (RX). The RX will use the direct information as the side information to decode the quantized signal from RN. Each of the relaying protocol has its features, which can be used in different application scenarios.

Recently, a large number of researches have been addressed the transmit power allocation (TPA) schemes for the relaying systems. In [4], the power allocation strategy for AF MIMO relaying system with single relay is investigated. [5] proposes the joint power assignment scheme in DF system where each node in the network is equipped with single antenna. In [6], the outage capacity of the HDF protocol is investigated, and in [7], an explicit adaptive frame resource allocation (AFRA) strategy is deduced in multi-relay systems, in which both CF and DF protocols are discussed. However, most of researches focus on designing the TPA schemes for AF and DF mode in single antenna scenario. In our previous work, [8] investigates the joint power and frame allocation scheme for cooperative CF relaying systems, and [9] proposes the TPA schemes for both HDF and DF scheme for multi-relay MIMO systems. To our knowledge, there is no work to discuss the TPA scheme of CF protocol in MIMO relaying systems.

Therefore, this paper focuses on exploiting the TPA schemes for different relaying protocols, i.e., CF and DF methods in MIMO cooperative relaying systems. The contributions of this paper are: 1) Firstly, we deduce a closed form of optimal TPA scheme by utilizing Lagrange function for each data stream of CF relaying mechanism. 2) A novel water-filling scheme is presented for DF protocol based on best node and antenna selection for each data stream, which can achieve significant capacity gain.

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The rest of the paper is organized as follows. In section II, the MIMO cooperative relaying systems are described. The detailed TPA schemes for CF and DF relaying are illustrated in section III. In section IV, the simulation results are deployed to validate the performance. Finally, the conclusions are drawn in Section V.

II. SYSTEM MODEL

The MIMO relaying model adopted in this paper is shown in Fig. 1. The analysis focuses on a two-hop relaying network which consists of a single source-destination pair with M antennas, and K relay nodes each carrying N antennas.

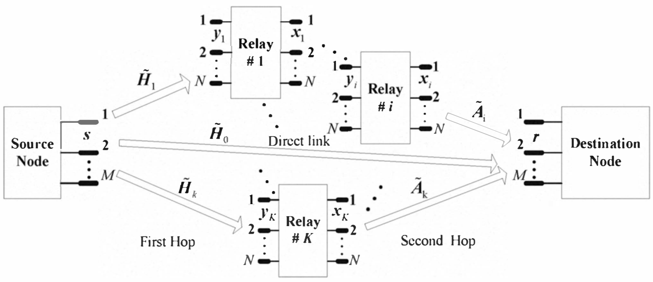

Figure 1. The MIMO cooperative relaying systems

The K relay nodes are assumed to be uniformly distributed in the middle region between the source and destination, where it is a circular region with the midpoint between TX and RX as the centre of a circle, and fractional distance between TX and RX as the radius. Assume the system adopts the half time division duplex (TDD) mechanism. In the first slot, the source broadcasts the data to relays and RX, and in the second slot, the relays forward the data to RX by utilizing the different relaying protocol. Besides, the direct link between the source and the destination node is considered, which means the destination can rely on the signals from both TX and relays through the combination. However, for simple analysis, the direct link is ignored first, and the impact of direct link will be discussed in Section IV. Furthermore, let $\mathrm{E}(\cdot)$ denote the expectation and $(\cdot)^H$ is the conjugate transpose.

According to the assumption, the source broadcasts an $\mathbf{M}\times 1$ data vector $\mathbf{s}$ to all relays in the first slot and the $\mathbf{N}\times 1$ received data vector $\mathbf{y}_k$ at the k-th relay can be expressed as

$$\mathbf{y}_k = \sqrt{\alpha_k}\mathbf{H}_k\mathbf{s} + \mathbf{n}_k = \tilde{\mathbf{H}}_k\mathbf{s} + \mathbf{n}_k \tag{1}$$

In the second slot, relay k processes the received data vector and forwards the corresponding transmit vector $\mathbf{x}_k$ to the destination. The signal vector received at the destination and the total power constraint at the relays are expressed as

$$\mathbf{r} = \sum_{k=1}^{K}\sqrt{\beta_k}\mathbf{A}_k\mathbf{x}_k + \mathbf{z} = \sum_{k=1}^{K}\tilde{\mathbf{A}}_k\mathbf{x}_k + \mathbf{z} \tag{2}$$

$$\sum_{k=1}^{K}\mathrm{E}\left[\mathbf{x}_k^H\mathbf{x}_k\right] = P_{RN} \tag{3}$$

In (1)-(3), $\mathbf{H}_k$ is an $\mathbf{N}\times\mathbf{M}$ channel matrix between the source and the k-th relay, and $\mathbf{A}_k$ is an $\mathbf{L}\times\mathbf{N}$ channel matrix between the k-th relay and the destination, with each entry set as identically independent distributed (i.i.d.) complex Gaussian random variables with unit variance. The total transmit power P_S is equally distributed among the M antennas on the source and the covariance matrix of $\mathbf{s}$ is $(P_S/M)\mathbf{I}_M$, and the P_{RN} is the total power for the K relay nodes. $\mathbf{n}_k$ is an $\mathbf{N}\times 1$ zero-mean mutually independent, circularly symmetric, complex Gaussian random vector at relay k with covariance matrix $\sigma_{k,r}\mathbf{I}_N$, where $\mathbf{I}_i$ is the $i\times i$ identity matrix. $\mathbf{z}$ is an $\mathbf{L}\times 1$ random vector with covariance matrix $\sigma_d\mathbf{I}_M$. For simplicity, we assume that $\sigma_{k,r}(k=1,\cdots,K)=\sigma_r$. Define α_k denotes the large-scale path loss between the source and relay k, β_k represents the large-scale path loss between relay k and RX, which can be expressed as

$$\alpha_k = \left(\frac{4\pi\lambda}{d_0}\right)^2 \cdot \left(\frac{d_0}{d_{k-sr}}\right)^\eta \cdot 10^{\xi_k/10} \tag{4}$$

$$\beta_k = \left(\frac{4\pi\lambda}{d_0}\right)^2 \cdot \left(\frac{d_0}{d_{k-rd}}\right)^\eta \cdot 10^{\xi_k/10} \tag{5}$$

where λ represents the wavelength of the carrier and d_0 is the reference distance. The scalar η denotes the path loss exponent. And the shadowing fading coefficient ξ_k is a zero-mean normal random variable with standard deviation δ. d_{k-sr} and d_{k-rd} denote the distances for S-R link and R-D link respectively.

Therefore, the optimization target of the MIMO relaying system is to maximize the system capacity of the total M data streams, that is

$$\text{Object: } \max\{C\} = \max\left\{\sum_{m=1}^{M} C_m\right\} \tag{6}$$

III. TRANSMIT POWER ALLOCATION SCHEMES FOR DIFFERENT RELAYING PROTOCOLS

A. The proposed TPA for CF relaying

In the case of CF relaying protocol, the RN quantifies the received signal from TX, and then forward to destination. The RX will use the direct information as the side information to decode the quantized signal from RN to obtain the performance gain. Therefore, the direct link is essential for CF relaying protocol. Assume $\mathbf{H}_0$ is an $\mathbf{M}\times\mathbf{M}$ channel matrix between the source and the RX. Note that the RN in CF relaying mode does not need to know the feedback of the direct link because of the fixed source coding in TX and fixed quantized modes [10].

When Gaussian codebooks are used, and the relay node compresses using Wyner-Ziv lossy source coding [10], the individual capacity of single link can be expressed as

$$C_{CF}=\frac{1}{2}\log_2\left(1+P_s\cdot|h_3|^2/N_0+\frac{P_s\cdot|h_1|^2/N_0}{1+\sigma_w^2}\right) \quad (7)$$

where σ_w^2 is the compressed noise, which can be expressed as

$$\sigma_w^2=\frac{P_s(|h_3|^2+|h_1|^2)/N_0+1}{P_r|h_2|^2/N_0(P_s|h_3|^2/N_0+1)} \quad (8)$$

According to Eq.(8), the capacity of the MIMO CF relaying system can be expressed as the similar form, that is

$$C_{CF}=\frac{1}{2}\log_2\det\left(\mathbf{I}_{M\times M}+\frac{P_s}{MN_0}\mathbf{H}_0\mathbf{R}_{xx}\mathbf{H}_0^{\dagger}+\frac{\frac{P_s}{MN_0}\mathbf{H}_1\mathbf{R}_{xx}\mathbf{H}_1^{\dagger}\cdot\mathbf{P}_{r-m}\cdot\mathbf{H}_2\widetilde{\mathbf{R}}_{xx}\mathbf{H}_2^{\dagger}}{1+\frac{P_s}{MN_0}\mathbf{H}_0\mathbf{R}_{xx}\mathbf{H}_0^{\dagger}+\frac{P_s}{MN_0}\mathbf{H}_1\mathbf{R}_{xx}\mathbf{H}_1^{\dagger}+\mathbf{P}_{r-m}\cdot\mathbf{H}_2\widetilde{\mathbf{R}}_{xx}\mathbf{H}_2^{\dagger}}\right) \quad (9)$$

where, $\mathbf{H}_1$, $\mathbf{H}_2$ are the channel matrices of the first link, second link respectively. $\mathbf{R}_{xx}$ is the covariance matrix of the transmit signal. $\mathbf{H}_1^{\dagger}$ denotes the pseudo-inverse of $\mathbf{H}_1$, where $\mathbf{H}_1^{\dagger}=\left(\mathbf{H}_1^H\mathbf{H}_1\right)^{-1}\mathbf{H}_1^H$. Therefore, for the *m*-th stream, the capacity of the *m*-th data stream using ZF through relay *k* can be expressed as

$$C_{CF-m}=\frac{1}{2}\log_2\left(1+\frac{P_s}{M\sigma_d^2\left\|\left(\tilde{\mathbf{H}}_0\right)_m^{\dagger}\right\|^2}+\frac{\frac{P_s}{M\sigma_r^2\sum_k\left\|\left(\tilde{\mathbf{H}}_k\right)_m^{\dagger}\right\|^2}\cdot\frac{P_{r-m}}{\sigma_d^2\sum_k\left\|\left(\tilde{\mathbf{A}}_k\right)_m^{\dagger}\right\|^2}}{1+\frac{P_s}{M\sigma_d^2\left\|\left(\tilde{\mathbf{H}}_0\right)_m^{\dagger}\right\|^2}+\frac{P_s}{M\sigma_r^2\sum_k\left\|\left(\tilde{\mathbf{H}}_k\right)_m^{\dagger}\right\|^2}+\frac{P_{r-m}}{\sigma_d^2\sum_k\left\|\left(\tilde{\mathbf{A}}_k\right)_m^{\dagger}\right\|^2}}\right) \quad (10)$$

In (10), $\|x\|$ stands for the Frobenius-norm of x. Therefore, the optimization target (6) can be rewritten as

$$\text{Object: } \max\{C_{CF}\}=\max\left\{\sum_{m=1}^{M}C_{CF-m}\right\} \quad (11)$$

$$\text{s.t. } \sum_{m=1}^{M}P_{r-m}=P_{RN} \quad (12)$$

Let

$$\alpha_m^2=\frac{1}{M\sigma_r^2\sum_k\left\|\left(\tilde{\mathbf{H}}_k\right)_m^{\dagger}\right\|^2} \quad (13)$$

$$\beta_m^2=\frac{1}{M\sigma_d^2\left\|\left(\tilde{\mathbf{H}}_0\right)_m^{+}\right\|^2} \quad (14)$$

$$\gamma_m^2=\frac{1}{\sigma_d^2\sum_k\left\|\left(\tilde{\mathbf{A}}_k\right)_m^{\dagger}\right\|^2} \quad (15)$$

Then, the Lagrange cost function $L\left(\left\{\sum C_{CF-m}\right\},\mu_{CF-m}\right)$ can be written as

$$L\left(\left\{\sum C_{CF-m}\right\},\mu_{CF-m}\right)=\sum_{m=1}^{M}\frac{1}{2}\log_2\left(1+P_s\cdot\beta_m^2+\frac{P_s\cdot\alpha_m^2\cdot P_{r-m}\cdot\gamma_m^2}{1+P_s\cdot\beta_m^2+P_s\cdot\alpha_m^2+P_{r-m}\cdot\gamma_m^2}\right)+\mu_{CF-m}\left(\sum_{m=1}^{M}P_{r-m}-P_{r,total}\right) \quad (16)$$

To obtain the first-order partial derivatives of L about P_{r-m}, it can be achieved that

$$\frac{\partial L}{\partial P_{r-m}}=\frac{1}{2}\ln 2\left(1+P_s\beta_m^2+\frac{P_s\alpha_m^2P_{r-m}\gamma_m^2}{1+P_s\beta_m^2+P_s\alpha_m^2+P_{r-m}\gamma_m^2}\right)^{-1}\cdot\left(\frac{P_s\alpha_m^2\gamma_m^2(1+P_s\beta_m^2+P_s\alpha_m^2+P_{r-m}\gamma_m^2)-P_s\alpha_m^2P_{r-m}\gamma_m^4}{(1+P_s\beta_m^2+P_s\alpha_m^2+P_{r-m}\gamma_m^2)^2}\right)-\mu_{CF-m}=0 \quad (17)$$

Therefore, the optimal TPA strategy on CF protocol can be solved according to (17), which can be expressed as

$$P_{r-m}=\left(\frac{-\left(\frac{X_m}{Y_m}+2\right)+\sqrt{\left(\frac{X_m}{Y_m}\right)^2+\frac{4X_m\cdot\ln 2}{\mu_{CF-m}}\left(1+\frac{X_m}{Y_m}\right)}}{2\left(X_m+Y_m\right)}\right)^{+} \quad (18)$$

$$X_m=\frac{P_s\alpha_m^2\gamma_m^2}{P_s(\alpha_m^2+\beta_m^2)+1} \quad (19)$$

$$Y_m=\frac{\gamma_m^2(P_s\beta_m^2+1)}{P_s(\alpha_m^2+\beta_m^2)+1} \quad (20)$$

where $(x)^{+}$ means to choose the maximum value between 0 and x. According to (18), the optimal TPA scheme for CF relaying protocol is achieved.

B. *The proposed TPA for DF relaying*

In previous work [9], a novel TPA scheme for DF protocol is proposed. However, the Best-Select One relay selection criterion is based on the SNR Γ_{m-sr} of the *m*-th data stream of the first hop, which can be denoted by

$$\Gamma_{m-sr}=\max_k\{\Gamma_{km-sr}\},\ RN_m=\arg\max_k\{\Gamma_{km-sr}\} \quad (21)$$

Actually, this selection may not choose the optimal relay node due to the capacity is constrained by the minimum one of the two hops in DF system. Thus, we are motivated to exploit a novel best relay node selection criterion.

Suppose the power the uniformly allocated for the relay nodes first. Then, the SNR of the two hops can be calculated. Assume Γ_{km-sr} is denoted by the SNR of the m-th stream from source node to relay k, and Γ_{km-rd} is denoted by the SNR of the m-th stream from relay k to RX. Thus, the capacity of the m-th stream through relay k is

$$C_{km-sd} = \min\left\{\frac{1}{2}\log_2\left(1+\Gamma_{km-sr}\right), \frac{1}{2}\log_2\left(1+\Gamma_{km-rd}\right)\right\} \quad (22)$$

Therefore, choose the best relay node for the m-th data stream according to

$$k = \arg\max_{k}\left\{C_{km-sd}\right\} \quad (23)$$

Therefore, based on the best relay node, the best antenna can be chosen in the k-th node. Since the channel capacity in DF relaying depends on the inferior link of the two hops, in most cases, is constrained by the second hop. Thus, the TPA scheme should be adjusted in order to achieve the efficiency of the power. And the procedure is the same as our previous work [9].

C. TPA Analysis for AF relaying

In the amplify-and-forward relaying scheme, the transmit signal of the k-th relay can be expressed as

$$\mathbf{x}_k = \rho_k\left(\tilde{\mathbf{H}}_k\mathbf{s}+\mathbf{n}_k\right) \quad (24)$$

Therefore, the received signal at RX can be expressed as

$$\mathbf{r} = \sum_{k=1}^{K}\tilde{\mathbf{A}}_k\mathbf{x}_k + \mathbf{z} = \sum_{k=1}^{K}\rho_k\tilde{\mathbf{A}}_k\tilde{\mathbf{H}}_k\mathbf{s} + \sum_{k=1}^{K}\rho_k\tilde{\mathbf{A}}_k\mathbf{n}_k + \mathbf{z} \quad (25)$$

To do pseudo-inverse based on ZF, the received signal can be re-written as:

$$\mathbf{r}' = \mathbf{s} + \left(\sum_{k=1}^{K}\rho_k\tilde{\mathbf{A}}_k\tilde{\mathbf{H}}_k\right)^{\dagger}\sum_{k=1}^{K}\rho_k\tilde{\mathbf{A}}_k\mathbf{n}_k + \left(\sum_{k=1}^{K}\rho_k\tilde{\mathbf{A}}_k\tilde{\mathbf{H}}_k\right)^{\dagger}\mathbf{z} \quad (26)$$

Where $\mathbf{r}' = \left(\sum_{k=1}^{K}\rho_k\tilde{\mathbf{A}}_k\tilde{\mathbf{H}}_k\right)^{+}\mathbf{r}$. Then the SNR for the m-th data stream at RX can be expressed as follows

$$\Gamma_m = \frac{P_s/M}{\sigma^2\sum_{k=1}^{K}\rho_k^2\left\|\left[\left(\sum_{k=1}^{K}\rho_k\tilde{\mathbf{A}}_k\tilde{\mathbf{H}}_k\right)^{\dagger}\tilde{\mathbf{A}}_k\right]_m\right\|^2 + \sigma^2\left\|\left(\sum_{k=1}^{K}\rho_k^2\tilde{\mathbf{A}}_k\tilde{\mathbf{H}}_k\right)^{\dagger}_m\right\|^2} \quad (27)$$

According to Eq.(27), it is difficult to obtain the close-form of ZF scheme for AF MIMO systems. Therefore, in order to exploit the simplest feature of AF system, the uniform PA is assumed, in which the ρ_k can be expressed as

$$\rho_k = \sqrt{\frac{P_{RN}/K}{\frac{P_s}{M}\left\|\tilde{\mathbf{H}}_k\right\|^2 + M\sigma^2}} \quad (28)$$

IV. SIMULATION RESULTS

The ergodic capacities of different relaying protocols are evaluated in frequency flat fading environment. In the simulation platform, the source, relay nodes and destination are all equipped with multiple antennas. The fading distributions between the tripartite (source to relays and relays to destination) are identical. The distance between the source and destination is assumed to be 500 meters. The transmit power constraints of source and relays are the same, i.e., $P_S = P_{RN}$. In order to validate the performance of the proposed schemes, the HDF scheme in [9] is also compared in our And the other simulation parameters are shown in Table I.

TABLE I. SIMULATION PATAMETERS

Parameter	Values
Propagation Distance	500m
RN Number of Interest	6
Antenna number in each node	{4,6}
Standard deviation of shadowing	8dB
Carrier Frequency	2GHz
Path-loss factor	4
do	10m
avg. Received SNR of Relay	{ -6dB ~ 6dB }
Simulation Trials	1000

Figure 2 and Figure 3 show the ergodic capacity comparison of different schemes under M=4 and K=6 scenarios. When the direct link is ignored, the capacity of CF system is higher than that of DF, HDF and AF systems. Compared with the DF system, the capacity gain of CF relaying protocol is nearly 14.2%. Secondly, the proposed OPA schemes outperform the UPA scheme in either of CF and DF relaying protocols. Furthermore, when the direct link is considered in HDF, DF, and AF schemes, the capacity of the HDF, AF and DF is increased by the effect of the direct transmission. Fortunately, the performance of the proposed TPA scheme of CF is also better than that of HDF and AF protocols. Based on the novel Best-Select-One scheme, the DF can achieve higher capacity when the average SNR is larger. That is because the proposed Best-Select-One scheme is much more effective when the average SNR is higher. When SNR=6dB, the performance gain of DF is 3% compared with CF systems.

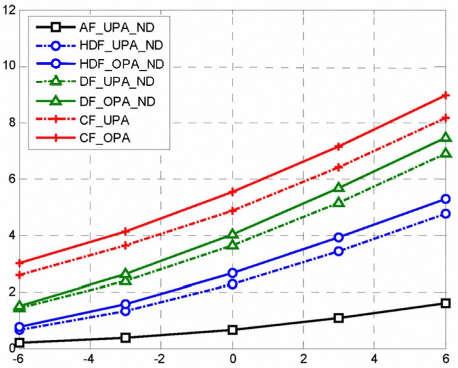

Figure 2. Ergodic capacity comparison of different schemes without diversity (M=4, K=6, and the direct link is ignored in DF, HDF, AF schemes)

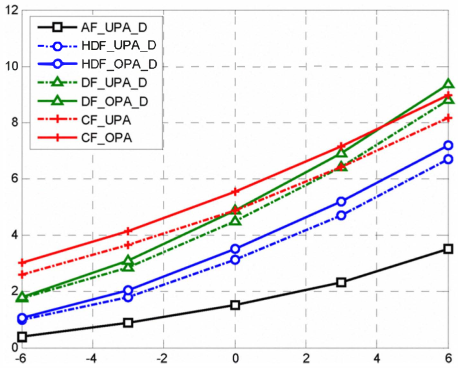

Figure 3. Ergodic capacity comparison of different schemes with diversity (M=4, K=6, and the direct link is considered in DF, HDF, AF schemes)

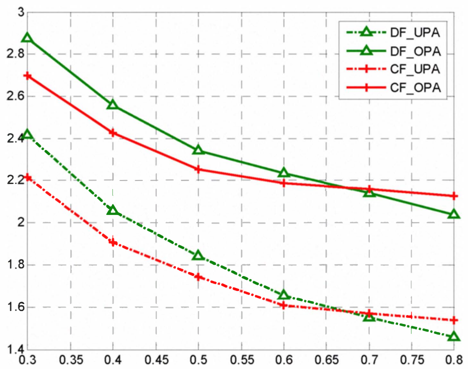

Figure 4. Ergodic capacity comparison of the CF and DF versus the relay distribution range (M=4, K=6, SNR=4dB)

Figure 4 shows the ergodic capacity comparison of the CF and DF system versus the relay distribution range when M=4, K=6. Figure 5 shows the similar comparison under M=6, K=6 case. It can be observed that when the relay node is deployed near the TX, the DF system achieves better performance than

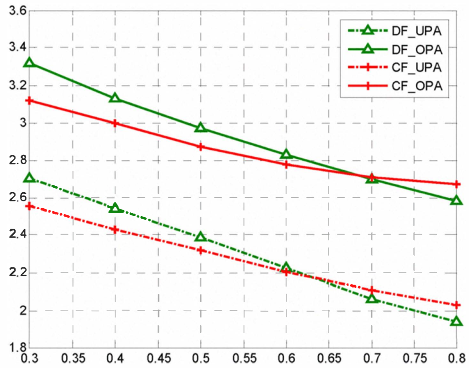

Figure 5. Ergodic capacity comparison of the CF and DF versus the relay distribution range (M=6, K=6, SNR=4dB)

CF; however, when the relays are relatively far from the TX, the CF yields better performance. Therefore, the CF protocol is a better choice for coverage extension for LTE-A systems.

V. Conclusion

In this paper, the TPA strategies for CF and DF relaying protocols are investigated for MIMO cooperative relaying systems. Two novel TPA schemes are proposed for CF and DF system, respectively. Simulation results show that the proposed TPA schemes can achieve obvious capacity gain, and the CF relaying protocol is a good candidate technology for coverage extension for LTE-A system.

References

[1] B. Wang, J. Zhang, and A. Host-Madsen, "On the capacity of MIMO relay channels," IEEE Trans. Inf. Theory, vol.51, no.1, pp.29-43, Jan. 2005.

[2] http://www.ieee802.org/16/relay.

[3] 3GPP TSG RAN WG1 meeting 57, R1-091803, "Understanding on Type 1 and Type 2 Relay", San Francisco, USA, May 2009.

[4] O. Munoz, J. Vidal, A. Agustin, "Non-regenerative MIMO relaying with channel state information", ICASSP IEEE Int Conf Acoust Speech Signal Process Proc, Philadelphia, USA. vol.3, pp.361-364, Mar, 2005.

[5] J. Luo, R. S. Blum, L. J. Cimini, et al. "Decode-and-forward cooperative diversity with power allocation in wireless networks", IEEE Int Conf Commun. vol. 6: pp. 793-799, Mar, 2007.

[6] Yijia Fan, J. S. Thompson, "On the outage capacity of MIMO multihop networks", IEEE Global Telecommunications Conference. St. Louis, USA. vol.4, pp. 2204-2208, Nov, 2005.

[7] Yang Ning, et al., "An Adaptive Frame Resource Allocation Strategy for TDMA-Based Cooperative Transmission," IEEE Communications Letters, vol.11, issue:5, pp. 417-419, May 2007.

[8] T. Wu, et al., "Joint Power and Frame Allocation for TDD-based Cooperative Relaying System" , IEEE ICCTA, Beijing, pp.101-105, Oct. 2009.

[9] J. Huang, et al., "On the Energy Efficiency of MIMO Cooperative Relaying Protocols", Journal of China Universities of Posts and Telecommunications, vol.16, no.2, pp.14-19, April. 2009.

[10] A.Wyner and J. Ziv, "The rate-distortion function for source coding with side information at the decoder," IEEE Trans. Inf. Theory, vol. IT-22, no.1, pp. 1-10, Jan. 1976.