다중-셀 이중-홉 MISO 릴레이 시스템에서 부분 채널 정보를 이용한 협력 전력 할당 기법

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Partial CSI-Based Cooperative Power Allocation in Multi-Cell Dual-Hop MISO Relay Systems

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요 약

본 논문은 다중 안테나를 가진 릴레이가 설치된 다중-셀 다중-사용자 시스템에서 부분 채널 정보를 이용하여 기지국과 릴레이 간 협력적으로 전력을 할당하는 기법을 제안한다. 이중-홉 MISO (Multi-Input Single-Output) 릴레이 채널에서, 릴레이 채널 용량(end-to-end capacity)을 최대화하기 위해 홉 간 송신 전력을 채널 상태에 따라 동적으로 할당할 필요가 있다. 제안된 기법은 목표 릴레이의 평균 채널 이득과 인접 릴레이로부터의 원하는 채널과 간섭 채널의 송신 상관 행렬의 주요한 고유벡터의 상대적인 각도 차이를 고려하여 릴레이 송신 전력을 동적으로 할당한다. 상향-경계치 분석을 통해서 릴레이 채널 용량은 원하는 채널과 간섭 채널의 주요한 고유벡터의 상대적인 각도 차이가 직교가 될 때 최대가 됨을 이론적으로 증명하였다.

Key Words : Cooperative transmission, MISO relay, partial CSI, power allocation, inter-relay interference

ABSTRACT

This paper proposes a cooperative power allocation with the use of partial channel information (e.g., the average signal-to-noise ratio (SNR) and transmit correlation) in multi-cell dual-hop multi-input single-output (MISO) relay systems. In a dual-hop MISO relay channel, it is desirable to allocate the transmit power between dual-hop links to maximize the end-to-end capacity. We consider the maximization of the end-to-end capacity of a dual-hop MISO relay channel under sum-power constraint. The proposed scheme adaptively allocates the transmit power considering the average channel gain of the target relay and the transmit correlation of the desired and inter-relay interference channel from adjacent relays. It is shown by means of upper-bound analysis that the end-to-end capacity can be maximized by making the angle difference of the principal eigenvectors of the desired and inter-relay interference channel orthogonal in highly-correlated channel environments. Finally, the performance of the proposed scheme is verified by computer simulation.

Ⅰ. Introduction

The use of wireless relays with multi-antennas, so-called multi-input multi-output (MIMO) relays,

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has received great attention in wireless networks (e.g., IEEE 802.16 WiMAX and 3GPP LTE standards) due to its potential for the enhancement of capacity and cell coverage[1]-[7]. Much effort has been concentrated on resource allocation to maximize the end-to-end capacity of a MIMO relay channel [8]-[13]. It has been shown that the end-to-end capacity of a MIMO relay channel can be increased by properly allocating the resource according to the channel condition[9].

The end-to-end capacity of a dual-hop MIMO relay channel can be improved by allocating the transmit power according to the average signal-to-noise ratio (SNR)[10]. However, the end-to-end capacity can be reduced due to the rank deficiency in the presence of channel correlation[12]. This problem can be alleviated by allocating the transmit power according to the correlation information as well as the average SNR[11],[12]. Nevertheless, the performance can be degraded in the presence of interference from adjacent relays, so-called inter-relay interference, in cellular environments [15],[16].

The use of coordinated eigen-beamforming can alleviate the inter-relay interference problem by making adjacent relays yield less interference to the target user[18]. It employs a collaborative scheduler that selects a pair of users, one from the target relay and the other from adjacent relay, whose principal eigenvectors yields the largest angle difference between them. The adjacent relay generates the beamforming weight in the direction of the principal eigenvector of the desired channel. However, it may not maximize the end-to-end capacity since the transmit power is allocated based on the average channel gain without taking the effect of inter-relay interference into consideration[18]. It may be desirable to allocate the transmit power jointly with the mitigation of inter-relay interference to maximize the end-to-end capacity.

In this paper, we propose a cooperative power allocation scheme based on partial channel state information (CSI) such as the average SNR and the transmit correlation in multi-cell multiuser dual-hop multi-input single-output (MISO) relay systems. We also consider the use of coordinated eigen-beamforming that can statistically avoid the interference[18]. The proposed scheme allocates the transmit power according to the angle difference of the principal eigenvector of the desired and interference channel as well as the average SNR. It can be shown by means of upper-bound analysis that the proposed scheme can maximize the end-to-end capacity by minimizing the inter-relay interference and allocating the transmit power when the principal eigenvectors of the desired and interference channel are orthogonal to each other.

The remainder of this paper is organized as follows. Section II describes a correlated multi-user dual-hop MISO relay channel in consideration. Section III briefly discusses conventional power allocation schemes. Section IV proposes a new power allocation strategy that maximizes the end-to-end capacity of a dual-hop MISO relay channel with the use of coordinated eigen-beamforming based on partial CSI. Section V verifies the analytic results by computer simulation. Finally, conclusions are given in Section VI.

Ⅱ. System model

We consider a correlated dual-hop MISO relay channel in multi-cell multi-user cellular systems as shown in Fig. 1, where the source $S^{(i)}$ transmits the signal using M_1 transmit antennas to relay $R^{(i)}$ by means of beamforming, the relay $R^{(i)}$ receives it using a single receive antenna and re-transmits it using M_2 transmit antennas to the destination $D^{(i)}$ by means of beamforming, and the destination $D^{(i)}$ receives it using a single receive antenna. We assume that the first and second hop equally share the channel bandwidth, and that the total power of the source and relay is P_0. We also assume that the direct link between the source and destination is unavailable due to large path loss.

Let $P_n^{(i)}$ and $\mathrm{w}_n^{(i)}$ be the transmit power and beamforming weight of the n-th hop, respectively, $s_{n,k^{(i)}}^{(i)}$ and $\mathrm{h}_{n,k^{(i)}}^{(i)}$ be the transmit signal and channel vector of the $k^{(i)}$-th destination in the i-th relay

$R^{(i)}$. Then, the received signal of the relay $R^{(i)}$ can be represented as

$$S^{(i)} \rightarrow R^{(i)} : y_1^{(i)} = \sqrt{u_{1,1}^{(i)} P_1^{(i)}} \mathbf{h}_{1,1}^{(i)} \mathbf{w}_1^{(i)} s_{1,1}^{(i)} + z_1^{(i)} \quad (1)$$

and the received signal of the $k^{(i)}$-th destination $D_{k^{(i)}}^{(i)}$ can be represented as

$$\begin{aligned} R^{(i)} \rightarrow D_{k^{(i)}}^{(i)} : y_2^{(i)} = & \sqrt{u_{2,k^{(i)}}^{(i)} P_2^{(i)}} \mathbf{h}_{2,k^{(i)}}^{(i)} \mathbf{w}_2^{(i)} s_{2,k^{(i)}}^{(i)} \\ & + \sqrt{u_{2,k^{(i)}}^{(j)} P_2^{(j)}} \mathbf{h}_{2,k^{(i)}}^{(j)} \mathbf{w}_2^{(j)} s_{2,k^{(j)}}^{(j)} + z_2^{(i)} \end{aligned} \quad (2)$$

where the first- and second-term in (2) denote the desired signal from $R^{(i)}$ to $D_{k^{(i)}}^{(i)}$ and the inter-relay interference signal from $R^{(j)}$ to $D_{k^{(i)}}^{(i)}$, respectively, $z_n^{(i)}$ denotes zero-mean additive white Gaussian noise (AWGN) with variance N_0 and $u_{n,k^{(i)}}^{(i)}\left(= d_{n,k^{(i)}}^{(i)^{-\beta}}\right)$ denotes the large-scale fading coefficient of the n-th hop. Here, $d_{n,k^{(i)}}^{(i)}$ is the propagation distance and β is the path loss exponent. To preserve the transmit power constraint, $\|\mathbf{w}_n^{(i)}\|_F$ is set to one, where $\|\mathbf{w}\|_F$ denotes the Frobenius norm of $\mathbf{w}$.

Assuming that each hop channel experiences spatially correlated Rayleigh fading, the channel vector $\mathbf{h}_{n,k^{(i)}}^{(i)}$ can be represented as[21]

$$\mathbf{h}_{n,k^{(i)}}^{(i)} = \mathbf{h}_{w,n,k^{(i)}}^{(i)} \mathbf{R}_{n,k^{(i)}}^{(i)/2} \quad (3)$$

where $\mathbf{h}_{w,n,k^{(i)}}^{(i)}$ denotes the uncorrelated channel vector, whose elements are independent and identically distributed (i.i.d) zero-mean complex Gaussian random variables with unit variance, and $\mathbf{R}_{n,k^{(i)}}^{(i)/2}$ denotes the square root of the transmit covariance matrix $\mathbf{R}_{n,k^{(i)}}^{(i)}$ defined by

$$\begin{aligned} \mathbf{R}_{n,k^{(i)}}^{(i)/2} &= E\left\{\mathbf{h}_{n,k^{(i)}}^{(i)*} \mathbf{h}_{n,k^{(i)}}^{(i)}\right\} \\ &= \begin{bmatrix} 1 & \cdots & \rho_{n,k^{(i)}}^{(i)M_n - 1} \\ \vdots & \ddots & \vdots \\ \rho_{n,k^{(i)}}^{*(i)M_n - 1} & \cdots & 1 \end{bmatrix}. \end{aligned} \quad (4)$$

Here, the superscript $*$ denotes conjugate transpose, $E\{\mathbf{x}\}$ denotes the expectation of $\mathbf{x}$, and $\rho_{n,k^{(i)}}^{(i)}\left(= \alpha_{n,k^{(i)}}^{(i)} e^{j\theta_{n,k^{(i)}}^{(i)}}\right)$ denotes the transmit correlation coefficient between adjacent antennas, where

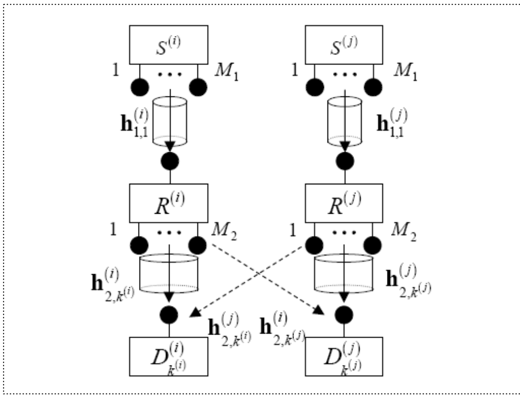

Fig. 1. A multi-cell dual-hop MISO relay

$\alpha_{n,k^{(i)}}^{(i)}\left(0 \le \alpha_{n,k^{(i)}}^{(i)} \le 1\right)$ and $\theta_{n,k^{(i)}}^{(i)}\left(0 \le \theta_{n,k^{(i)}}^{(i)} \le 2\pi\right)$ denote its amplitude and phase, respectively. Since $\mathbf{R}_{n,k^{(i)}}^{(i)}$ is a positive semi-definite Hermitian matrix, it can be decomposed as[22]

$$\mathbf{R}_{n,k^{(i)}}^{(i)} = \mathbf{U}_{n,k^{(i)}}^{(i)} \Sigma_{n,k^{(i)}}^{(i)} \mathbf{U}_{n,k^{(i)}}^{(i)*} \quad (5)$$

where $\mathbf{U}_{n,k^{(i)}}^{(i)} = \left[\mathbf{u}_{n,k^{(i)},1}^{(i)}, \mathbf{u}_{n,k^{(i)},2}^{(i)}, \ldots, \mathbf{u}_{n,k^{(i)},M_n}^{(i)}\right]$ is an $M_n \times M_n$ unitary matrix whose columns are the normalized eigenvectors of $\mathbf{R}_{n,k^{(i)}}^{(i)}$ and $\Sigma_{n,k^{(i)}}^{(i)}$ is an $M_n \times M_n$ diagonal matrix whose diagonal elements $\left\{\lambda_{n,k^{(i)},1}^{(i)}, \lambda_{n,k^{(i)},2}^{(i)}, \ldots, \lambda_{n,k^{(i)},M_n}^{(i)}\right\}$ are descending ordered non-negative real values, i.e., $\lambda_{n,k^{(i)},1}^{(i)} \ge \lambda_{n,k^{(i)},2}^{(i)} \ge \ldots \ge \lambda_{n,k^{(i)},M_n}^{(i)} \ge 0$. We define the principal eigenvector corresponding to the largest eigenvalue $\lambda_{n,k^{(i)},1}^{(i)}$ of $\mathbf{R}_{n,k^{(i)}}^{(i)}$ by $\mathbf{u}_{n,k^{(i)},\max}^{(i)}$ (i.e., $\mathbf{u}_{n,k^{(i)},1}^{(i)} = \mathbf{u}_{n,k^{(i)},\max}^{(i)}$).

Ⅲ. Previous works

In this section, we briefly review conventional power allocation schemes for easy description of the proposed scheme.

3.1 Average SNR-based power allocation

In an uncorrelated dual-hop MISO relay channel, the transmit power for the first- and second-hop can be determined as [10]

$$\left(P_{1,SNR}^{(i)}, P_{2,SNR}^{(i)}\right) = \left(\frac{P_0}{1 + \sqrt[3]{A_{SNR}}}, \frac{P_0}{1 + \sqrt[3]{A_{SNR}^{-1}}}\right) \quad (6)$$

where $A_{SNR}=\left(\frac{d_{1,1}^{(i)}}{d_{2,k^{(i)}}^{(i)}}\right)^{-\beta}\frac{E\left\{\sqrt{\|\mathbf{h}_{1,1}^{(i)}\|}\right\}}{E\left\{\sqrt{\|\mathbf{h}_{2,k^{(i)}}^{(i)}\|}\right\}}$. Here, $E\left\{\sqrt{\|h_{n,k^{(i)}}^{(i)}\|}\right\}=\left(\frac{\Gamma(M_n+1/2)}{\Gamma(M_n)}\right)$, $\Gamma(x)$ denotes Gamma function [10]. It can be seen that $P_{n,SNR}^{(i)}$ is inversely proportional to the average channel gain of the n-th hop.

3.2 Correlation-based power allocation

In a correlated dual-hop MISO relay channel, the eigen-beamforming can maximize the received SNR of each hop with the use of the transmit correlation[18]. The transmit power is determined by maximum eigenvalue of the transmit correlation matrix as well as the average SNR of $\mathbf{h}_{1,1}^{(i)}$ and $\mathbf{h}_{2,k^{(i)}}^{(i)}$ as [11]

$$\left(P_{1,corr}^{(i)},P_{1,corr}^{(i)}\right)=\left(\frac{P_0}{1+A_{corr}},\frac{P_0}{1+A_{corr}^{-1}}\right) \tag{7}$$

where $A_{corr}=\frac{\lambda_{1,1,\max}^{(i)}}{\lambda_{2,k^{(i)},\max}^{(i)}}\left(\frac{d_{1,1}^{(i)}}{d_{2,k^{(i)}}^{(i)}}\right)^{-\beta}$. When $M_1=M_2=2$, $A_{corr}=\frac{\left(1+\alpha_{1,1,\max}^{(i)}\right)}{\left(1+\alpha_{2,k^{(i)},\max}^{(i)}\right)}\left(\frac{d_{1,1}^{(i)}}{d_{2,k^{(i)}}^{(i)}}\right)^{-\beta}$ since $\lambda_{n,k^{(i)},\max}^{(i)}=1+\alpha_{n,k^{(i)}}^{(i)}$ for $M_n=2$ [4]. It can be seen that the transmit power can simply be determined by the $\alpha_{1,1}^{(i)},\alpha_{2,k^{(i)}}^{(i)}$ and $d_{1,1}^{(i)^{-\beta}},d_{2,k^{(i)}}^{(i)^{-\beta}}$.

Ⅳ. Proposed scheme

In this section, we consider partial CSI-based power allocation in a dual-hop MISO relay channel. We first derive the end-to-end capacity of a dual-hop MISO relay with the use of coordinated eigen-beamforming, and then determine the transmit power to maximize the end-to-end capacity.

4.1 Upper-bound analysis of end-to-end capacity

In a correlated single-user MISO relay channel, the beamforming weight can be determined by the principal eigenvector of the transmit correlation matrix of each hop when the transmit correlation is available to the transmitter. The end-to-end capacity of the $k^{(i)}$-th destination is upper-bound by [5],[16]

$$C_{k^{(i)},EBF}^{(i)}\le\min\left[\begin{array}{l}\log_2\left(1+\gamma_{1,1}^{(i)}\lambda_{1,1,\max}^{(i)}\right),\\ \log_2\left(1+\gamma_{2,k^{(i)}}^{(i)}\lambda_{2,k^{(i)},\max}^{(i)}\right)\end{array}\right] \tag{8}$$

where $\gamma_{1,1}^{(i)}=u_{1,1}^{(i)}P_1^{(i)}/N_0$ and $\gamma_{2,k^{(i)}}^{(i)}=u_{2,k^{(i)}}^{(i)}P_2^{(i)}/N_0$. Notice that this upper-bound may not be achievable in practice due to the inter-relay interference [15],[16].

It has been shown that the inter-relay interference can be minimized by means of coordinated eigen-beamforming[18]. Its end-to-end capacity is upper-bounded by

$$C_{k^{(i)},Coop.EBF}^{(i)}\le\min\left[\begin{array}{l}\log_2\left(1+\gamma_{1,1}^{(i)}\alpha_{1,1}^{(i)}\right),\\ \log_2\left(1+\frac{\gamma_{2,k^{(i)}}^{(i)}\left(1+\alpha_{2,k^{(i)}}^{(i)}\right)}{\gamma_{2,k^{(i)}}^{(j)}\left(1+\alpha_{2,k^{(i)}}^{(j)}\cos\triangle\theta_2^{j}\right)+1}\right)\end{array}\right] \tag{9}$$

where $\triangle\theta_2^{(j)}\left(=|\theta_{2,k^{(j)}}^{(j)}-\theta_{2,k^{(i)}}^{(j)}|\right)$ denotes the phase difference between $\mathbf{h}_{2,k^{(j)}}^{(j)}$ and $\mathbf{h}_{2,k^{(i)}}^{(j)}$. It can be seen that $C_{k^{(i)},Coop.EBF}^{(i)}$ is maximized when the principal eigenvectors of $\mathbf{h}_{2,k^{(j)}}^{(j)}$ and $\mathbf{h}_{2,k^{(i)}}^{(j)}$ are orthogonal to each other (i.e., $\triangle\theta_2^{(j)}=\pi$ [19]).

4.2 Proposed cooperative power allocation

Since the inter-relay interference severely affects the end-to-end capacity, it may be desirable to allocate the transmit power considering the inter-relay interference to balance the capacity of dual-hops. In fact, the end-to-end capacity is determined by the minimum capacity of dual-hops [5]. It is desirable to allocate the total power to maximize the minimum capacity. Fig. 2 illustrates that the end-to-end capacity depends on the transmit power of the source and relay as well as the channel condition of dual-hops, and that the optimum allocation is determined by the crossing point of the end-to-end capacity curve and the sum-power constraint. Thus, the optimum power allocation problem can be formulated as

$$\begin{aligned}C_{k^{(i)},pro}^{(i)}&=\max C_{k^{(i)},Coop.EBF}^{(i)}\left(P_1^{(i)},P_2^{(i)}\right)\\&=\max\min\left[C_{1,pro}^{(i)}\left(P_1^{(i)}\right),C_{2,pro}^{(i)}\left(P_2^{(i)}\right)\right]\end{aligned} \tag{10}$$

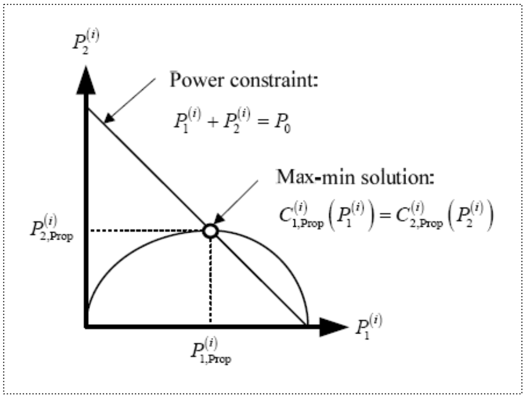

Fig. 2. Design concept of the proposed scheme

where $P_1^{(i)} + P_2^{(i)} = P_0$. It can be shown that $C_{k^{(i)},pro}^{(i)}$ can be maximized by making [20]

$$C_{1,pro}^{(i)}\left(P_1^{(i)}\right) = C_{2,pro}^{(i)}\left(P_2^{(i)}\right) \tag{11}$$

Assuming that $M_1 = M_2 = 2$, it can be shown that the transmit power can be determined as

$$\begin{aligned} &For\ A \neq 0,\\ &\left(P_{1,pro}^{(i)}, P_{2,pro}^{(i)}\right) = \left(P_0 - \frac{B - \sqrt{B - 4AC}}{2A}, \frac{-B + \sqrt{B - 4AC}}{2A}\right)\\ &For\ A = 0,\\ &\left(P_{1,pro}^{(i)}, P_{2,pro}^{(i)}\right) = \left(P_0 - \left|\frac{C}{B}\right|, \left|\frac{C}{B}\right|\right) \end{aligned} \tag{12}$$

where

$$A = u_{1,1}^{(i)} u_{2,k^{(i)}}^{(i)} \left(1 + \alpha_{1,1}^{(i)}\right)\left(1 + \alpha_{2,k^{(i)}}^{(j)} \cos \triangle\theta_2^{(j)}\right) \tag{13}$$

$$\begin{aligned} B = {} & u_{1,1}^{(i)}\left(1 + \alpha_{1,1}^{(i)}\right)N_0 + u_{2,k^{(i)}}^{(i)}\left(1 + \alpha_{2,k^{(i)}}^{(i)}\right)N_0 - \\ & u_{1,1}^{(i)}\left(1 + \alpha_{1,1}^{(i)}\right)u_{2,k^{(i)}}^{(j)}\left(1 + \alpha_{2,k^{(i)}}^{(j)}\cos\triangle\theta_2^{(j)}\right)P_0 \end{aligned} \tag{14}$$

$$C = -u_{1,1}^{(i)}\left(1 + \alpha_{1,1}^{(i)}\right)P_0 N_0 \tag{15}$$

Proof: In the coordinated eigen-beamforming, the condition satisfying (11) is given by

$$r_{1,1}^{(i)}\left(1 + \alpha_{1,1}^{(i)}\right) = \frac{r_{2,k^{(i)}}^{(i)}\left(1 + \alpha_{2,k^{(i)}}^{(i)}\right)}{r_{2,k^{(i)}}^{(j)}\left(1 + \alpha_{2,k^{(i)}}^{(j)}\cos\triangle\theta_2^{(j)}\right) + 1}. \tag{16}$$

From $\gamma_{n,k^{(i)}}^{(i)} = u_{n,k^{(i)}}^{(i)} P_n^{(i)} / N_0$ and $P_1^{(i)} + P_2^{(i)} = P_0$, (16) can be rewritten as

$$AP_2^{(i)2} + AP_2^{(i)} + C = 0. \tag{17}$$

If $A \neq 0$, the optimum transmit power can be determined by

$$\left(P_{1,pro}^{(i)}, P_{2,pro}^{(i)}\right) = \left(P_0 - \frac{B - \sqrt{B^2 - 4AC}}{2A}, \frac{B - \sqrt{B^2 - 4AC}}{2A}\right) \tag{18}$$

Otherwise,

$$\left(P_{1,pro}^{(i)}, P_{2,pro}^{(i)}\right) = \left(P_0 - \left|\frac{C}{B}\right|, \left|\frac{C}{B}\right|\right). \tag{19}$$

It can be seen that the transmit power can be optimally determined by the average channel gain, the correlation amplitude, and the phase difference of the transmit correlation coefficient between the desired and interference channel from $R^{(j)}$. In fact, $P_{n,pro}^{(i)}$ is inversely proportional to the capacity of the n-th hop. As $\triangle\theta_2^{(j)}$ increases, $C_{2,pro}^{(i)}$ increases due to the reduction of inter-relay interference. In this case, it needs to decrease $P_{2,pro}^{(i)}$ while increasing $P_{1,pro}^{(i)}$ to balance the capacity of dual-hops, and vice versa. When $\triangle\theta_2^{(j)} = \pi$ and $\alpha_{2,k^{(i)}}^{(j)} = 1$ (i.e., $A = 0$), the proposed scheme provides an end-to-end capacity nearly similar to the correlation-based scheme. This is mainly because the inter-relay interference can almost be eliminated in an average sense, so the transmit power of the two schemes becomes equal. The overall procedure of the proposed scheme is summarized in Fig. 3.

V. Simulation results

The analytic results and the performance of the proposed scheme are verified by computer simulation. For comparison, the performance of the average SNR-based[10] and the correlation-based power allocation scheme[11] is also considered. The common simulation parameters are summarized in Table 1.

Fig. 4 depicts the performance of the proposed scheme in a correlated dual-hop MISO relay channel according to $\triangle\theta_2^{(j)}$ when $d_{1,1}^{(i)} = d_{1,1}^{(j)} = 0.7$ km,

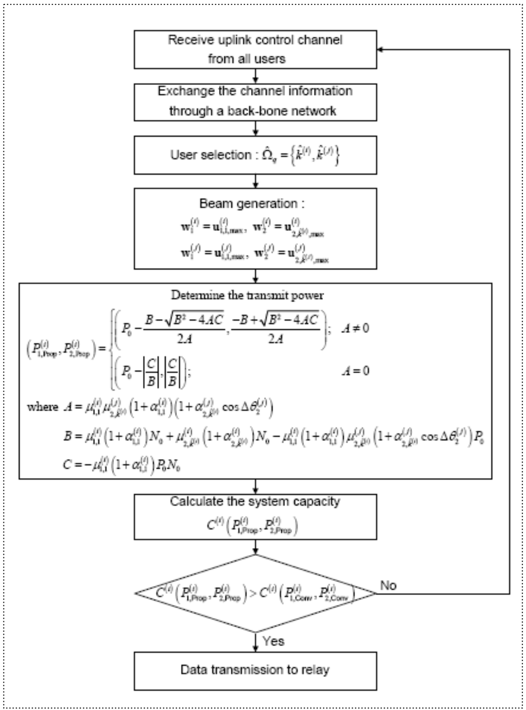

Fig. 3. Overall procedure of the proposed scheme

$d_{2,k^{(i)}}^{(i)} = d_{2,k^{(j)}}^{(i)} = 0.3$ km, $\alpha_{1,1}^{(i)} = \alpha_{1,1}^{(j)} = 0.7$, $\alpha_{2,k^{(i)}}^{(i)} = \alpha_{2,k^{(j)}}^{(i)} = \alpha_{2,k^{(j)}}^{(j)} = \alpha_{2,k^{(j)}}^{(j)} = 0.9$, and $\gamma_0 = 0$ dB. It can be seen that unlike other two schemes, the proposed scheme adaptively allocates the transmit power according to $\triangle\theta_2^{(j)}$. It can also be seen that the capacity of the second hop increases due to the reduction of the inter-relay interference from $\mathrm{R}^{(j)}$ as $\triangle\theta_2^{(j)}$ increases. This implies that it needs to

Table 1. Simulation parameters

Parameters	Values
Cell configuration	2-cells, 2-relays
Cell radius	1 km
Frequency reuse	1
Fading channel	Spatially correlated Rayleigh fading
Path loss	4
Link adaptation	Ideal (i.e., using the Shannon's capacity formular)
Comparison schemes	Average SNR-based PA [10] Correlation-based PA [11]

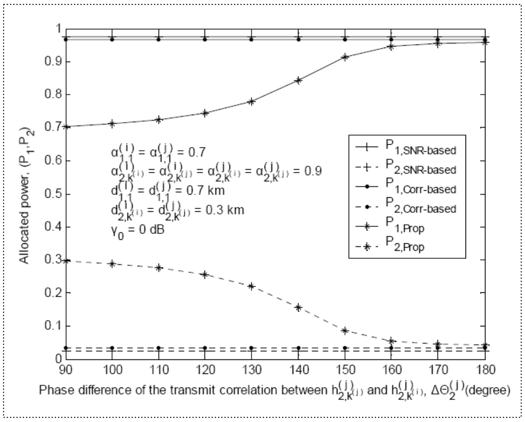

Fig. 4-a. Allocated transmit power according to $\triangle\theta_2^{(j)}$.

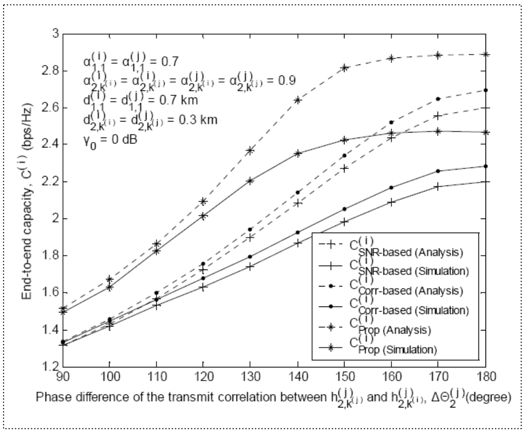

Fig. 4-b. End-to-end capacity according to $\triangle\theta_2^{(j)}$.

decrease $P_{2,\mathrm{Prop}}^{(i)}$ while increasing $P_{1,\mathrm{Prop}}^{(i)}$. It can also be seen that the proposed scheme noticeably outperforms the other two schemes. This is mainly due to the power gain obtained by allocating the transmit power considering the inter-relay interference channel condition.

Fig. 5 depicts the performance of the proposed scheme according to γ_0 when $d_{1,1}^{(i)} = d_{1,1}^{(j)} = 0.7$ km, $d_{2,k^{(i)}}^{(i)} = d_{2,k^{(j)}}^{(i)} = 0.3$ km, $\alpha_{1,1}^{(i)} = \alpha_{1,1}^{(j)} = 0.7$, $\alpha_{2,k^{(i)}}^{(i)} = \alpha_{2,k^{(j)}}^{(i)} = \alpha_{2,k^{(j)}}^{(j)} = \alpha_{2,k^{(j)}}^{(j)} = 0.9$, and $\triangle\theta_2^{(j)} = \pi$. It can be seen that the proposed scheme outperforms the other two schemes; yielding a spectral efficiency enhancement of 0.182 bps/Hz (or 8.1 % improvement) and 0.40 bps/Hz (or 10.6 % improvement) over the correlation-based scheme

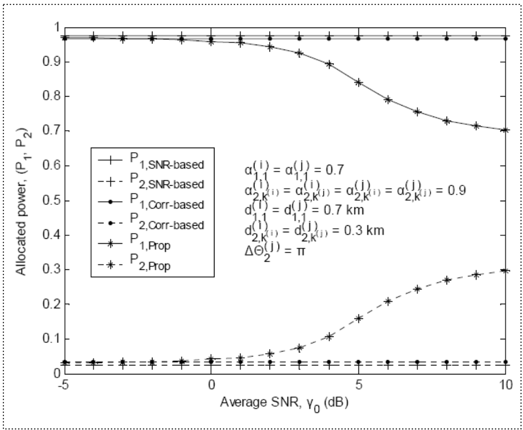

Fig. 5-a. Allocated transmit power according to γ_0.

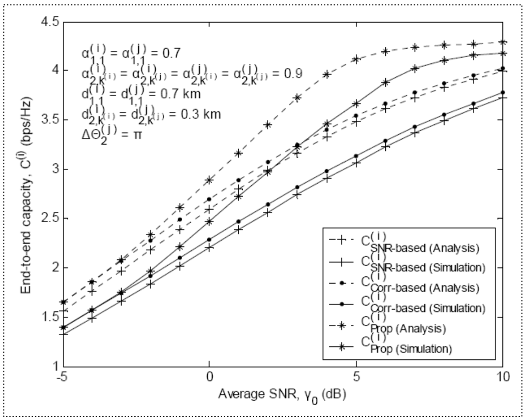

Fig. 5-b. End-to-end capacity according to γ_0.

without increase of the total transmit power when $\gamma_0 = 0$ dB and $\gamma_0 = 10$ dB, respectively. It can also be seen that the proposed scheme provides nearly the same performance as the correlation-based scheme when γ_0 is very low. This is mainly because both schemes similarly allocate the transmit power in noise-dominant environments.

Ⅵ. Conclusions

In this paper, we have proposed a cooperative power allocation strategy that controls the transmit power considering the inter-relay interference channel condition in multi-cell dual-hop MISO relay systems. The proposed scheme dynamically allocates the transmit power according to the correlation amplitude and the angle difference of the principal eigenvectors of the desired and interference channel as well as the average channel gain. It has been shown that the proposed scheme maximizes the end-to-end capacity by making the angle difference orthogonal in highly correlated channel environments. Numerical results show that the proposed scheme can provide noticeable performance improvement over the conventional SNR-based and the correlation-based schemes in interference-limited channel environments.

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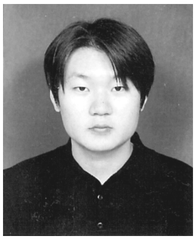

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