ICT-MobileSummit 2009 Conference Proceedings
Paul Cunningham and Miriam Cunningham (Eds)
IIMC International Information Management Corporation, 2009
ISBN: 978-1-905824-12-0

Power Allocation for Nonregenerative Cooperative MIMO Communication under Various Levels of Channel State Information

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Abstract: This paper proposes various power allocation algorithms for nonregenerative cooperative multi-input multi-output system, which have been optimised based on mutual information for different levels of channel state information (CSI) available at the base station (BS) and at the relay station (RS). Four different CSI settings have been studied in this paper : CSI of both the first and second hop channels known at the BS; CSI of the first hop channel known at the BS and CSI of the second hop channel known at the RS; CSI of both the first and second hop channels known at the RS; and only CSI of the first hop channel known at the RS. The performance of our algorithms have been compared against some previous power allocation methods as well as brute-force power allocation for each of these settings, in order to demonstrate their efficiency.

Keywords: Cooperative communication, amplify and forward, multi-input multi-output (MIMO), power allocation

1. Introduction

Cooperative communication has recently attracted considerable research interests [1–6]. In a simple cooperation scenario composed of a base station (BS) node, a single relay station (RS) and a mobile station (MS), three main links are established, i.e., BS-MS, BS-RS, and RS-MS links. Various approaches have been followed to design cooperative multi-input multi-output (MIMO) communication systems, the most notorious ones are decode and forward (DF) and as amplify and forward (AF) [1–3,6]. DF is a regenerative approach where the full decoding of the source message followed by the forwarding of the whole message to the destination node via the relay node are performed. On the contrary, AF is a simple nonregenerative approach where the relay node amplifies and forwards the signal received from the source node.

In cooperative scenario, the relay can be utilised as a smart precoder that allows mutual information improvement through efficient power allocation techniques based on the level of CSI available at the RS, instead of being used as a complex encoder/decoder system or as a dumb amplifier [7, 8]. In this paper, the AF approach has been chosen since it is well-suited for integrating precoding at the RS, and four different levels of CSI have been considered with various degrees of feasibility: CSI of both the first and second hop channels known at the BS; CSI of the first hop channel known at the BS and CSI of the second hop channel known at the RS; CSI of both the first and second hop channels known at the RS; and only CSI of the first hop channel known at the RS. The first case is hardly feasible in reality but serves as a benchmark. In the second and third scenario, CSI can be obtained by reciprocity, and in the fourth scenario CSI can be easily obtained via pilot symbol. Notice that the fourth scenario is the one considered for traditional AF.

In this paper we design optimised power allocation algorithms for nonregenerative cooperative MIMO system, relying on the system model introduced in Section 2. In Section 3, we introduce our algorithms for each of the four CSI levels previously described. In Section 4, we show the efficiency of our algorithm by comparing their performance in terms of mutual information against brute-force algorithms and other existing algorithm available in the literature. Finally, conclusions are drawn in Section 5.

2. System model for cooperative MIMO communication

We consider a cooperative MIMO communication system composed of three nodes, where a BS equipped with n antennas cooperates with a nonregenerative RS equipped with q antennas to transmit/receive data to/from a MS equipped with p antennas, as depicted in Fig. 1.

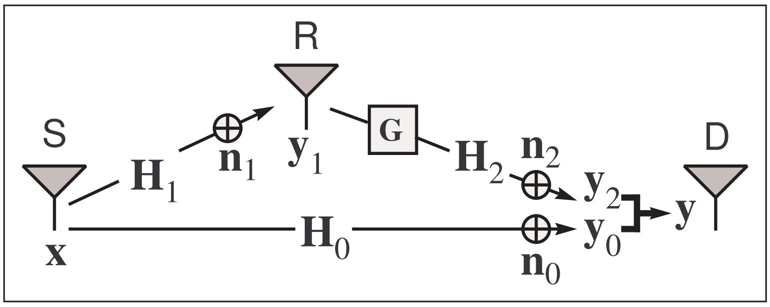

Figure 1: Nonregenerative cooperative MIMO communication system model.

For the simplicity of the introduction, we assume a half duplex relaying scenario with two equal duration phases as in [7, 8], where in the first phase the BS broadcasts the signal $\mathbf{x}$ to the MS and the RS, and in the second phase only the RS transmits to the MS. During the first phase, the signal $\mathbf{x}$ is received as $\mathbf{y}_0 = \mathbf{H}_0\mathbf{x} + \mathbf{n}_0$ and $\mathbf{y}_1 = \mathbf{H}_1\mathbf{x} + \mathbf{n}_1$ at the MS and RS, respectively, where $\mathbf{H}_0 \in \mathbb{C}^{p\times n}$ and $\mathbf{H}_1 \in \mathbb{C}^{q\times n}$ characterise the MIMO channel between the BS-MS and BS-RS links, respectively. During the second phase, the signal $\mathbf{y}_1$ is refined by using the precoding matrix $\mathbf{G} \in \mathbb{R}^{q\times q}$, then is transmitted towards the MS, and is received as $\mathbf{y}_2 = \mathbf{H}_2\mathbf{G}\mathbf{y}_1 + \mathbf{n}_2$, where $\mathbf{H}_2 \in \mathbb{C}^{p\times q}$ characterises the MIMO channel between the RS-MSs link. Moreover $\mathbf{n}_0 \in \mathbb{C}^p$, $\mathbf{n}_1 \in \mathbb{C}^q$ and $\mathbf{n}_2 \in \mathbb{C}^p$ are vectors of independent zero-mean complex Gaussian noise entries with a variance of σ^2. The system model of the cooperative MIMO communication system introduced in Fig. 1 can be summarised as follows

$$\mathbf{y} = \begin{bmatrix} \mathbf{y}_0 \\ \mathbf{y}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{H}_0 \\ \mathbf{H}_2\mathbf{G}\mathbf{H}_1 \end{bmatrix} \mathbf{x} + \begin{bmatrix} \mathbf{I}_p & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{H}_2\mathbf{G} & \mathbf{I}_p \end{bmatrix} \begin{bmatrix} \mathbf{n}_0 \\ \mathbf{n}_1 \\ \mathbf{n}_2 \end{bmatrix}, \tag{1}$$

with $\mathbf{I}_p$ is a $p \times p$ identity matrix. Consequently, the aggregate mutual information of the cooperative communication system in Fig. 1 can be expressed as [9]

$$I(\mathbf{y}; \mathbf{x}) = \frac{1}{2} \log_2 \left| \mathbf{I}_{2p} + \mathbf{H}\mathbf{R}_x\mathbf{H}^\dagger\mathbf{R}_n^{-1} \right|, \tag{2}$$

where

$$\mathbf{H} = \begin{bmatrix} \mathbf{H}_0 \\ \mathbf{H}_2\mathbf{G}\mathbf{H}_1 \end{bmatrix}, \mathbf{R}_n = \begin{bmatrix} \mathbf{R}_{n_0} & \mathbf{0} \\ \mathbf{0} & \mathbf{H}_2\mathbf{G}\mathbf{R}_{n_1}\mathbf{G}^\dagger\mathbf{H}_2^\dagger + \mathbf{R}_{n_2} \end{bmatrix},$$

$\mathbf{H}^\dagger$ denotes the conjugate transpose of $\mathbf{H}$, $\mathbf{R}_x = \mathrm{E}\left\{\mathbf{x}\mathbf{x}^\dagger\right\}$ is the transmit signal covariance matrix, $\mathbf{R}_{n_0} = \mathbf{R}_{n_2} = \sigma^2\mathbf{I}_p$ and $\mathbf{R}_{n_1} = \sigma^2\mathbf{I}_q$ are noise covariance matrices, and $\sigma = 1$. Notice that the factor $1/2$ in (2) accounts for the 2-phases transmission.

Recently in [7], the aggregate mutual information $I(\mathbf{y};\mathbf{x})$ has been shown to be bounded as $I(\mathbf{y}_0;\mathbf{x}) + I(\mathbf{y}_2;\mathbf{x}) \geq I(\mathbf{y};\mathbf{x}) \geq I(\mathbf{y}_2;\mathbf{x})$, where $I(\mathbf{y}_0;\mathbf{x})$ is the mutual information of the direct link and $I(\mathbf{y}_2;\mathbf{x})$ the mutual information of the relay link given by

$$\begin{aligned} I(\mathbf{y}_0;\mathbf{x}) &= \frac{1}{2}\log_2\left|\mathbf{I}_{2p} + \mathbf{H}_0\mathbf{R}_x\mathbf{H}_0^\dagger\mathbf{R}_{n_0}^{-1}\right|, \\ I(\mathbf{y}_2;\mathbf{x}) &= \frac{1}{2}\log_2\left|\frac{\mathbf{R}_{n_2} + \mathbf{H}_2\mathbf{G}(\mathbf{H}_1\mathbf{R}_x\mathbf{H}_1^\dagger + \mathbf{R}_{n_1})\mathbf{G}^\dagger\mathbf{H}_2^\dagger}{\mathbf{R}_{n_2} + \mathbf{H}_2\mathbf{G}\mathbf{R}_{n_1}\mathbf{G}^\dagger\mathbf{H}_2^\dagger}\right|, \end{aligned} \tag{3}$$

respectively. Therefore, the aggregate mutual information $I(\mathbf{y};\mathbf{x})$ can be increased by maximising $I(\mathbf{y}_2;\mathbf{x})$ in (3) and hence by optimising $\mathbf{G}$, when $\mathbf{H}_0$ is unknown.

3. Power allocation algorithm for various levels of CSI

In this section, we consider four levels of CSI and provide algorithm to optimise the precoding matrix $\mathbf{G}$ in any of these cases assuming that the average transmission power at the BS and RS, i.e., P_1 and P_2, respectively. The BS and RS power constraints denoted P_{BS} and P_{RS}, respectively, can be expressed as follows

$$P_{\text{BS}} : \mathrm{E}\{\|\mathbf{x}\|_F^2\} \leq P_1,\ P_{\text{RS}} : \mathrm{E}\{\|\mathbf{G}(\mathbf{H}_1\mathbf{x} + \mathbf{n}_1)\|_F^2\} \leq P_2, \tag{4}$$

where $\mathrm{E}\{.\}$ is the expectation and $\|.\|_F$ is the Frobenius norm.

3.1 Full CSI at BS

We first consider the case of full CSI (FCSI) at BS, where $\mathbf{H}_1$ and $\mathbf{H}_2$ are both know at the BS. In this case both matrices can be decomposed via singular valued decomposition as $\mathbf{H}_1 = \mathbf{U}_1\mathbf{\Lambda}_1^{\frac{1}{2}}\mathbf{V}_1^\dagger$ and $\mathbf{H}_2 = \mathbf{U}_2\mathbf{\Lambda}_2^{\frac{1}{2}}\mathbf{V}_2^\dagger$, respectively, where $\mathbf{U}_1 \in \mathbb{C}^{q\times q}$, $\mathbf{V}_1 \in \mathbb{C}^{n\times n}$, $\mathbf{U}_2 \in \mathbb{C}^{p\times p}$ and $\mathbf{V}_2 \in \mathbb{C}^{q\times q}$ are unitary matrices. Moreover, $\mathbf{\Lambda}_1 \in \mathbb{C}^{q\times n}$ and $\mathbf{\Lambda}_2 \in \mathbb{C}^{p\times q}$ are rectangular diagonal matrices with nonnegative diagonal elements $\lambda_{1,i}$ and $\lambda_{2,i}$, respectively, which are sorted in descending order as in [7]. This ordering has been shown to be close to optimal in [7]. Furthermore, we consider that $\mathbf{G} = \mathbf{V}_2\widetilde{\mathbf{G}}\mathbf{U}_1^\dagger$ with $\widetilde{\mathbf{G}} = \mathrm{diag}(\sqrt{p_{2,1}}, \sqrt{p_{2,1}}, \ldots, \sqrt{p_{2,q}})$ is a $q \times q$ diagonal matrix, and that $\mathbf{x} = \mathbf{V}_1\mathbf{D}\mathbf{s}$ where $\mathbf{D} = \mathrm{diag}(\sqrt{p_{1,1}}, \sqrt{p_{1,1}}, \ldots, \sqrt{p_{1,n}})$ is a $n\times n$ diagonal matrix, $\mathbf{s} \in \mathbb{C}^n$, $\mathrm{E}\{\mathbf{s}\mathbf{s}^\dagger\} = 1$, and we define $N = \min\{n, q, p\}$. Consequently, we can re-express (3) after some simplifications as

$$I(\mathbf{y}_2;\mathbf{x}) = \frac{1}{2}\sum_{i=1}^{N}\log_2(1 + p_{1,i}\eta_{1,i}), \text{with } \eta_{1,i} = \frac{\lambda_{1,i}\lambda_{2,i}p_{2,i}}{1 + \lambda_{2,i}p_{2,i}}. \tag{5}$$

In order to obtain the $p_{1,i}$ and $p_{2,i}$ that maximise (4), we must solve the following optimisation problem

$$\begin{aligned} &\max_{p_{1,i},p_{2,i}} \sum_{i\in[1,N]} \log_2(1 + p_{1,i}\eta_{1,i}) \\ &\text{s.t. } p_{1,i}, p_{2,i} \geq 0, i \in [1, N], P_{\text{BS}}, P_{\text{RS}}. \end{aligned} \tag{6}$$

This problem requires the optimisation of two set of variables at the same time and it cannot be solved by directly using classic convex optimisation [10]. However, we solve it in a simple recursive fashion by splitting it into two parts. First, we assume that $p_{2,i}$ is known in $\eta_{1,i}$ (5), and then we optimise the $p_{1,i}$ values by solving the classic water-filling problem

$$\begin{aligned} &\max_{p_{1,i}} \sum_{i\in[1,N]} \log_2(1+p_{1,i}\eta_{1,i}) \\ &\text{s.t. } p_{1,i} \geq 0, i \in [1,N], P_{\text{BS}} \end{aligned} \tag{7}$$

for which a straightforward solution is given by $p_{1,i} = \max(\xi_1^\star - 1/\eta_{1,i}, 0)$, with $\xi_1^\star$ being the water line. At this point we denote S the set of indices i for which $p_{1,i} \neq 0$. Using the result of (7) in (6), we then optimise the $p_{2,i}$ values by solving the following concave problem

$$\begin{aligned} &\max_{p_{2,i}} \sum_{i\in\mathcal{S}} \log_2(\xi_1^\star \lambda_{1,i}) + \log_2\left(\frac{\lambda_{2,i}p_{2,i}}{1+\lambda_{2,i}p_{2,i}}\right) \\ &\text{s.t. } p_{2,i} \geq 0, i \in S, P_{\text{RS}}. \end{aligned} \tag{8}$$

Applying the Karush-Kuhn-Tucker (KKT) conditions [10] to (7), we obtain after simplifications that $p_{2,i} = \left(-1+\sqrt{1+\frac{4\lambda_{2,i}\xi_2^\star}{1+p_{1,i}\lambda_{1,i}}}\right)/(2\lambda_{2,i})$ with $\xi_2^\star$ is such that $f(\xi_2^\star) = 0$ where

$$f(\xi_2) = \sum_{i\in\mathcal{S}} \left(-1+\sqrt{1+\frac{4\lambda_{2,i}\xi_2}{1+\lambda_{1,i}p_{1,i}}}\right)(1+\lambda_{1,i}p_{1,i})/(2\lambda_{2,i}) - P_2. \tag{9}$$

The values of $p_{2,i}$ can then be used in (6) to obtain $p_{1,i}$, and so on and so forth until (4) converge. The algorithm can be summarised as follows

Algorithm 1

1: **while** $N > 1$ **do**
2: Set $I = 0$, $S = [1, N]$, $p_{2,i} = P_2/N, \forall i \in S$
3: Calculate $\eta_{1,i}$
4: Water-filling: $p_{1,i} = \max(\xi_1^\star - 1/\eta_{1,i}, 0) \Rightarrow N = |\{p_{1,i}|p_{1,i} > 0\}|$, resize S
5: Solve $f(\xi_2) = 0$ using the Newton– Raphson method [11] $\Rightarrow \xi_2^\star$
6: Calculate $p_{2,i}$ using the value of $\xi_2^\star$
7: Set $\widehat{I} = I$
8: Calculate $I = \sum_{i\in S} \log_2(1+p_{1,i}\eta_{1,i})/2$
9: **if** $I - \widehat{I} < \epsilon$ **then** Set $I_{\text{MAX},N} = \widehat{I}$, $N = N-1$, **go to** 1
10: **else go to** 3
11: **end while**
12: $I_{\text{MAX},1} = \log_2(1+P_1\lambda_{1,1})/2 + \log_2(1+P_2\lambda_{2,1})/2 - \log_2(1+P_1P_2\lambda_{1,1}\lambda_{2,1})/2$
13: $I(\mathbf{y}_2;\mathbf{x}) = \max_j(I_{\text{MAX},j})$

3.2 Transmit CSI at BS and RS

We consider, in this subsection, the case of independent transmit CSI (TCSI) at BS and RS, where $\mathbf{H}_1$ is known at the BS and $\mathbf{H}_2$ is known at the RS. As for the previous case both matrices can be decomposed via singular valued decomposition, i.e., $I(\mathbf{y}_2;\mathbf{x})$ can be simplified as in (5), then the optmisation problem is the same as in (5) and it can also be split into two parts. However in the first part, we solve the water-filling problem in (7) using $\lambda_{1,i}$ instead of $\eta_{1,i}$ to obtain the $p_{1,i}$ values, since the $\lambda_{2,i}$ values are not known at the BS. We then solve the optimisation problem in (8) to obtain the

$p_{2,i}$ values. Notice that no recursions are required here since the two optimisation parts are independent. The algorithm can be summarised as

Algorithm 2

1: **while** $N > 1$ **do**
2: $S = [1, N]$
3: Water-filling: $p_{1,i} = \max(\xi_1^\star - 1/\lambda_{1,i}, 0) \Rightarrow N = |\{p_{1,i} | p_{1,i} > 0\}|$, resize S
4: Solve $f(\xi_2) = 0$ using the Newton– Raphson method [11] $\Rightarrow \xi_2^\star$
5: Calculate $p_{2,i}$ using the value of $\xi_2^\star$
6: Calculate $I_{\text{MAX},N} = \sum_{i \in S} \log_2(1 + p_{1,i}\eta_{1,i})/2$
7: $N = N - 1$
8: **end while**
9: $I_{\text{MAX},1} = \log_2(1 + P_1\lambda_{1,1})/2 + \log_2(1 + P_2\lambda_{2,1})/2 - \log_2(1 + P_1P_2\lambda_{1,1}\lambda_{2,1})/2$
10: $I(\mathbf{y}_2; \mathbf{x}) = \max_j(I_{\text{MAX},j})$

3.3 Full CSI at RS

In the case that FCSI is available at RS, i.e., both $\mathbf{H}_1$ and $\mathbf{H}_2$ are both know at the RS, then the optimisation problem simplifies as in (8) with $p_{1,i} = P_1/N, \forall i \in [1, N]$. Algorithm 2 can then be used without step 3 and with $p_{1,i}$ values set prior to the while loop at step 0. We denote this modified version of Algorithm 2 as Algorithm 3.

3.4 Receive CSI at RS

The most practical of these cases is when only received CSI (RCSI) is known at the RS, i.e., only $\mathbf{H}_1$ is known at the RS. In this case, techniques that already exist in the literature such as AF, matched filtering MF detection or minimum mean square error MMSE detection can be straightforwardly used to design $\mathbf{G}$ as

$$\mathbf{G} = \sqrt{P_2}\mathbf{J}\left(\mathrm{E}\left\{\| \mathbf{J}(\mathbf{H}_1\mathbf{x} + \mathbf{n}_1) \|_F^2\right\}\right)^{-\frac{1}{2}}, \tag{10}$$

where $\mathbf{J} = \mathbf{I}_q$ for AF, $\mathbf{J} = \mathbf{H}_1^\dagger$ for MF, and $\mathbf{J} = (P_1/q)\mathbf{H}_1^\dagger\left[(P_1/q)\mathbf{H}_1\mathbf{H}_1^\dagger + \mathbf{I}_q\right]^{-1}$ for MMSE.

Here we propose a novel method to optimise $\mathbf{G}$ based on the expectation of $I(\mathbf{y}_2; \mathbf{x})$ over $\mathbf{H}_2$. In the case that only $\mathbf{H}_1$ is known at the RS, $I(\mathbf{y}_2; \mathbf{x})$ in (3) can first be re-expressed as

$$I(\mathbf{y}_2; \mathbf{x}) = \frac{1}{2}\log_2\left|\mathbf{I}_p + \mathbf{H}_2\widetilde{\mathbf{F}}\widetilde{\mathbf{F}}^\dagger\mathbf{H}_2^\dagger\right| - \frac{1}{2}\log_2\left|\mathbf{I}_p + \mathbf{H}_2\widetilde{\mathbf{G}}\widetilde{\mathbf{G}}^\dagger\mathbf{H}_2^\dagger\right|, \tag{11}$$

where $\widetilde{\mathbf{G}} = \mathbf{G}\mathbf{U}_1$ and $\widetilde{\mathbf{F}} = \widetilde{\mathbf{G}}((P_1/q)\mathbf{\Lambda}_1 + \mathbf{I}_q)^{\frac{1}{2}}$. Using the result (21) in [12] for $n = 1$, $m = q$, $\alpha = 1$, $\beta = p$, $\omega = \sqrt{1/\delta_1}$, and $\upsilon_i = \delta_1/\delta_i$ it can be shown that $\mathrm{E}\left\{\log_2\left|\mathbf{I}_N + \mathbf{H}_2\mathbf{\Delta}\mathbf{H}_2^\dagger\right|\right\}$ is asymptotically equivalent to

$$\chi(\delta) = \frac{k+q}{2}\log_2(\delta_1) - \sum_{i=1}^{q}\log_2\left(\frac{\delta_1}{\sqrt{\delta_1} + d_0\delta_i}\right) - q\log_2\left(\frac{d_0}{q}\right) - \frac{1}{\ln(2)}\sum_{i=1}^{q}\frac{d_0\delta_i}{\sqrt{\delta_1} + d_0\delta_i} \tag{12}$$

for large number of k and q values, where $\mathbf{\Delta} = \mathrm{diag}(\delta)$ is a $q \times q$ diagonal matrix, $\delta = \{\delta_1, \delta_2, \ldots, \delta_q\}$, and d_0 is the only nonnegative root of the polynomial given by

$$P(d) = \left(\frac{d}{\sqrt{\delta_1}} - q\right)\prod_{i=1}^{q}\left(\frac{\sqrt{\delta_1}}{\delta_i} + d\right) + d\sum_{i=1}^{q}\prod_{\substack{j=1 \\ j \neq i}}^{q}\left(\frac{\sqrt{\delta_1}}{\delta_j} + d\right). \tag{13}$$

Then by solving the following optimisation problem

$$\begin{aligned} &\max_{\mathbf{p_2}} [\chi(\mathbf{p_2}((P_1/q)\mathbf{\Lambda}_1 + \mathbf{I}_q)) - \chi(\mathbf{p_2})]/2, \\ &\text{s.t. } p_{2,i} \geq 0, i \in S, \sum_{i \in \mathcal{S}} p_{2,i}(1 + \lambda_{1,i}(P_1/q)) \leq P_2, \end{aligned} \tag{14}$$

where $\mathbf{p_2} = \{p_{2,1}, p_{2,2}, \ldots, p_{2,q}\}$, we obtain the $p_{2,i}$ values that maximise $\mathrm{E}\{I(\mathbf{y}_2; \mathbf{x})\}_{\mathbf{H}_2}$.

4. Numerical results

The various power allocation methods introduced in Section 3., i.e., Algorithm 1 (Alg1), Algorithm 2 (Alg2), Algorithm 3 (Alg3), AF, MF, MMSE, and (14), are evaluated here in terms of mutual information performance considering cooperative, i.e., $I(\mathbf{y}; \mathbf{x})$, and non-cooperative, i.e., $I(\mathbf{y}_2; \mathbf{x})$, settings, and are compared against brute-force (BF) algorithm and the method proposed in [7, 8] for the case of FCSI at the RS. In BF algorithm, all the possible values of $p_{2,i}$ and $p_{1,i}$ are enumerated for any realisation of the channels. BF is optimal but very time consuming and can only be applied for very low values of N. BF is here used as a benchmark. Moreover, in our simulation, we consider SNR_0 as the signal-to-noise ratio (SNR) between the BS and the MSs, SNR_1 as the SNR between the BS and the RS, and SNR_2 as the SNR between the RS and the MSs.

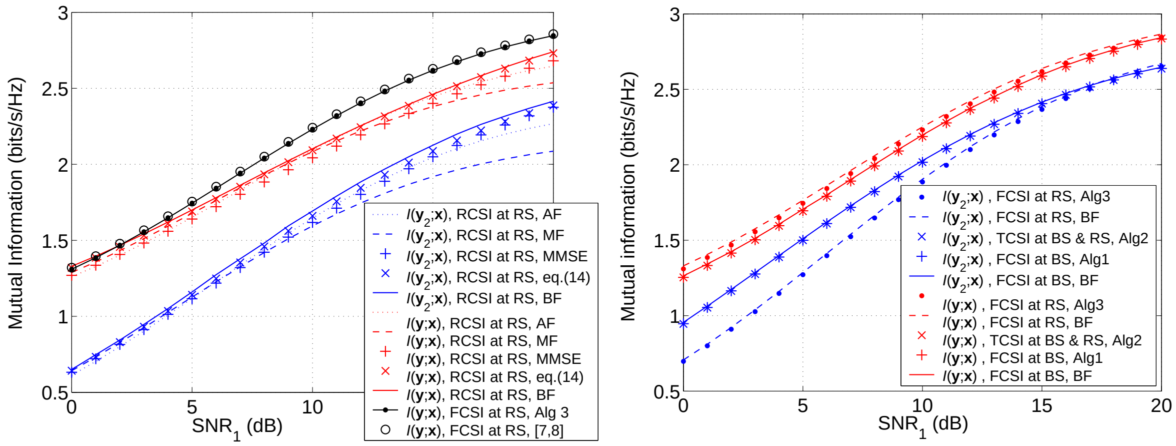

Figure 2: Mutual information performance of various power allocation algorithms for $n = q = p = 2$, SNR_0=0 dB and SNR_2=10 dB.

In Fig. 2, we compare the cooperative and non-cooperative mutual information performance of various power allocation algorithms for $n = q = p = 2$, $\mathrm{SNR}_0 = 0$ dB and SNR_2=10 dB. On the left side of Fig. 2, for the case of RCSI at RS studied in Section 3.4, our results indicate that our novel method proposed in (14) outperforms AF, MF, and MMSE for cooperative and non-cooperative communications and it provides performance close to optimal, i.e., close to the one of BF. Also, the performance of our novel method is closed to that of Alg3 at low SNR_1. Otherwise, the results show that Alg3 performs as good as [7, 8] and BF algorithms.

The right side of Fig. 2 indicates first that Alg1 and BF performs the same in the case of FCSI at BS. Moreover, the results show that Alg1 performance can be achieved with less complexity using Alg2, since they both perform similarly. As expected Alg1 and Alg2 outperform Alg3 in non-cooperative case since they have been designed to maximise $I(\mathbf{y}_2; \mathbf{x})$. However, in the cooperative case, it turns out that Alg3 outperforms both Alg1 and Alg2, but the performance difference decreases as SNR_1 (dB) increases. Modifying the power allocation at the BS has an impact on the direct link performance and the results pinpoint that as long as the quality of the relay link is not drastically better than that of the direct link, i.e., SNR_1=SNR_2 >SNR_0 + 20 dB, then it is not efficient to optimise the power allocation solely according to the relay link at the BS.

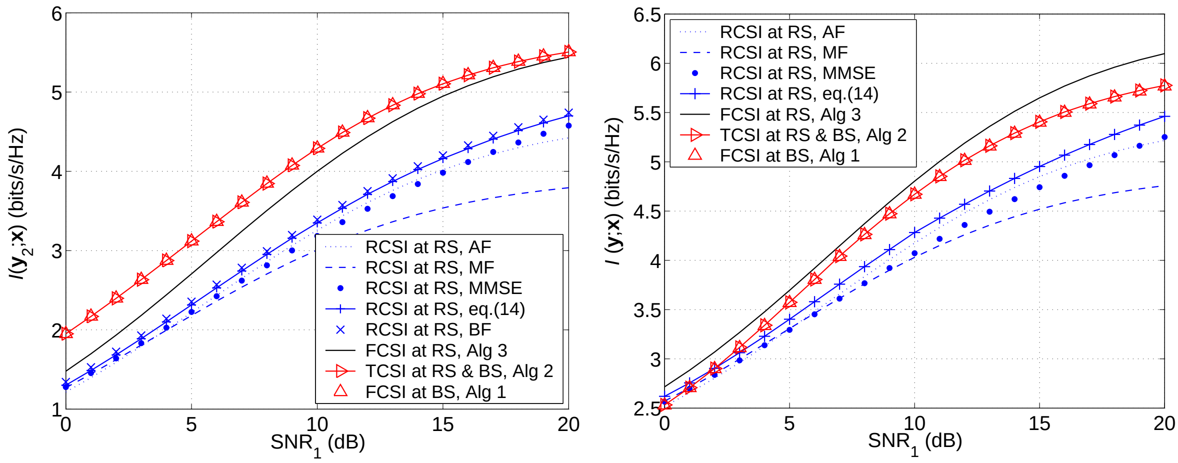

Figure 3: Non-cooperative (left) and Cooperative (right) Mutual information performance of various power allocation algorithms for $n = q = p = 4$, SNR_0=0 dB and SNR_2=10 dB.

In Fig. 3, we compare the cooperative and non-cooperative mutual information performance of various power allocation algorithms for $n = q = p = 4$, SNR_0=0 dB and SNR_2=10 dB. For the non-cooperitave case, on the left side of Fig. 3, the results confirm that our power allocation method in (14) provides close to optimal performance when only RCSI available at RS, that Alg2 provides the same performance as Alg1 with less complexity, and that Alg1 and Alg2 outperforms Alg3. Concerning the cooperative case on the right side of Fig. 3, it can be noticed that the performance gap between Alg1 and Alg3 is larger than in the $n = q = p = 2$ case. By increasing the number of antennas, the number of eigenmodes increases, and more of these modes are not properly tuned for the direct link when Alg1 or Alg2 is utilised, which further reduces the efficiency of this link compare to the $n = q = p = 2$ case.

5. Conclusion

In this paper various power allocation algorithms for multiuser nonregenerative cooperative system have been presented. They have been designed to optimise the mutual information of the relay link for different levels of CSI available at the BS and RS when the direct link channel is unknown. Simulation results have shown that in the most realistic case, i.e., RCSI available only at the relay, our novel proposed power allocation method outperforms any other methods. We have also proposed two algorithms, i.e., Alg1 and Alg2, which are more efficient than Alg1 when the relay link has a drastically better quality than the direct link, i.e., SNR_1=SNR_2 >$\text{SNR}_0 + 20$ dB. Furthermore, we have established that Alg3 should be utilised instead of Alg1 or Alg2 when the relay and direct link has similar quality. In this case, Alg1 and Alg2 miss the CSI of the direct link in order to be adequately optimised. Thus, in the future, CSI of the direct link will be used at the BS to design an enhanced version of algorithm Alg2.

Acknowledgment

This work has been performed in the framework of the FP7 project ROCKET IST-215282 STP, which is funded by the European Community.

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