Optimal Power Schedule for Distributed MIMO Links

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***Abstract*— In this paper, we study a wireless network of distributed MIMO links that are located in a neighborhood with mutual interference. We aim to develop an optimal power schedule (OPS) to maximize a total throughput of the network. Our proposed OPS allows the source covariance matrices of all MIMO links to vary within a block of time slots. This new approach exploits both the spatial and temporal freedoms of distributed MIMO links. Our results show that the new approach outperforms the existing ones.**

I. Introduction

A multiple-input multiple-output (MIMO) wireless link is well known to provide a much higher capacity than a single-input single-output (SISO) wireless link in a scattered environment. Many coding and modulation techniques for a MIMO link have been developed in the past several years.

However, for a wireless network of multiple distributed MIMO links, such as a network in the future combat systems, there are new issues of research. The existing MIMO theory is not sufficient for such a wireless network where multiple MIMO links cause mutual interferences to each other.

This problem was recognized by Demirkol and Ingram in [1] and further addressed by Ye and Blum in [2]. In both works, the source covariance matrix $\mathbf{P}_i$ of the ith MIMO link is assumed to be independent of time. In [1], $\mathbf{P}_i$ for $i = 1, 2, ..., L$ are sequentially and iteratively optimized with respect to the capacity of individual MIMO links. The solution of this method is also called Nash equilibrium. In [2], $\mathbf{P}_i$ for $i = 1, 2, ..., L$ are jointly searched using the gradient descent of the sum capacity of all L MIMO links. It turns out that the gradient method generally yields a better solution than the Nash equilibrium.

In this paper, we propose a new approach to design the source covariance matrices of distributed MIMO links. We allow the source covariance matrices to be functions of time within a block of time slots. The utilization of the temporal freedom makes it possible to achieve a higher sum (or averaged) capacity of the distributed MIMO links. Thus, the new approach is interesting for the wireless networks in the future combat systems.

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II. The problem formulation

Let us consider a wireless communication network with M nodes. Each node has N antennas. At each time slot, there are L concurrent links. Each active source node (SN) delivers information only to one active destination node (DN). And each active DN receives information only from one active SN. Therefore, there are maximal $\lfloor M/2 \rfloor$ simultaneous MIMO links, where $\lfloor x \rfloor$ denotes the maximal integer no greater than x. The vector of the received signal $\mathbf{y}_i$ at the ith DN can be written as

$$\mathbf{y}_i = \sqrt{\frac{\rho_i}{N}}\mathbf{H}_{i,i}\mathbf{x}_i + \sum_{j=1,j\neq i}^{L}\sqrt{\frac{\beta_{i,j}}{N}}\mathbf{H}_{i,j}\mathbf{x}_j + \mathbf{v}_i \qquad (1)$$

where $\mathbf{H}_{i,j}, i,j = 1,\cdots,L$ is the $N \times N$ channel matrix between the jth SN and the ith DN, ρ_i denotes the signal-to-noise ratio (SNR) of the ith link, $\beta_{i,j}, j = 1,\cdots,L, j \neq i$ is the interference-to-noise ratio (INR) of the jth SN to the ith DN, $\mathbf{x}_i$ denotes the $N \times 1$ vector of the normalized transmitted signal from the ith SN, and $\mathbf{v}_i$ is the $N \times 1$ vector of the i.i.d. additive white Gaussian noise (AWGN) with zero mean and covariance matrix $\mathbf{C}_{\mathbf{v}_i} = \mathbf{I}_N$. Here $\mathbf{I}_N$ denotes the $N \times N$ identity matrix. We assume that all the normalized transmitted signal is Gaussian distributed with zero mean vector and covariance matrix $\mathbf{P}_i \triangleq \mathrm{E}\{\mathbf{x}_i\mathbf{x}_i^H\}$, where $\mathrm{E}\{\cdot\}$ stands for the statistical expectation, and $(\cdot)^H$ denotes the matrix Hermitian transpose. Without any loss of generality, we assume that $\mathrm{tr}\{\mathbf{P}_i\} = N, i = 1,\cdots,L$, where $\mathrm{tr}\{\cdot\}$ stands for the trace of a matrix.

From (1), we can write the interference-plus-noise covariance matrix $\mathbf{R}_i$ at the ith DN as

$$\mathbf{R}_i = \sum_{j=1,j\neq i}^{L}\frac{\beta_{i,j}}{N}\mathbf{H}_{i,j}\mathbf{P}_j\mathbf{H}_{i,j}^H + \mathbf{I}_N\,. \qquad (2)$$

For simplicity, let us assume that the interfering signals are unknown to the receiver, and single user receiver is used at each DN. Thus, for a given set of $\mathbf{P}_l, l = 1,\cdots,L$, the mutual information of the ith MIMO link can be written as

$$I_i(\mathbf{P}_1,\cdots,\mathbf{P}_L) = \log_2\left|\mathbf{I}_N + \frac{\rho_i}{N}\mathbf{H}_{i,i}\mathbf{P}_i\mathbf{H}_{i,i}^H\mathbf{R}_i^{-1}\right| \qquad (3)$$

where $|\cdot|$ denotes the determinant of a matrix. Similarly, the overall mutual information of the whole L MIMO links can be represented as

$$I(\mathbf{P}_1,\cdots,\mathbf{P}_L) = \sum_{i=1}^{L}\log_2\left|\mathbf{I}_N + \frac{\rho_i}{N}\mathbf{H}_{i,i}\mathbf{P}_i\mathbf{H}_{i,i}^H\mathbf{R}_i^{-1}\right|\,. \qquad (4)$$

The algorithm proposed in [2] aims to find the covariance matrices $\mathbf{P}_i, i = 1, \cdots, L$, such that they maximize (4). It can be formulated as the following optimization problem

$$\max_{\mathbf{P}_1,\cdots,\mathbf{P}_L} \; I(\mathbf{P}_1, \cdots, \mathbf{P}_L) \tag{5}$$

$$\text{s.t. } \operatorname{tr}\{\mathbf{P}_i\} = N, \quad \mathbf{P}_i \geq 0, \qquad i = 1, \cdots, L\,. \tag{6}$$

An inherent drawback of the problem formulation (5)-(6) is that only one time slot is considered for signal transmission. In other words, all the SNs are scheduled to transmit in each time slot. However, it can be seen from (4) that with the increasing transmission power of all SNs, the overall system will be interference limited. Therefore, in the case of strong interference, it is suboptimal to schedule all SNs to transmit simultaneously in each time slot. It is of great interest to employ power schedule schemes to mitigate the interfering signal components. In fact, when the interference is sufficiently high (or the links are very close to each other), we show in the journal paper [3] that it is optimal to schedule the transmission power orthogonally using the time-division multiple access (TDMA) where during one time slot, only one SN is transmitting to its DN.

III. The new approach

We assume that the channel is quasi-static which remains invariant for L contiguous time slots. Let us consider the averaged overall system mutual information

$$R(\mathcal{P}) = \frac{1}{L}\sum_{t=1}^{L}\sum_{i=1}^{L}\log_2\left|\mathbf{I}_N + \frac{\rho_i}{N}\mathbf{H}_{i,i}\mathbf{P}_i(t)\mathbf{H}_{i,i}^H\mathbf{R}_i^{-1}(t)\right| \tag{7}$$

where for the notational simplicity, we introduce

$$\mathcal{P} \triangleq \{\mathbf{P}_i(t), i, t = 1, \cdots, L\}\,.$$

In this paper, we propose an OPS approach. It can be formulated as the following optimization problem

$$\max_{\mathcal{P}} \; R(\mathcal{P}) \tag{8}$$

$$\text{s.t. } \frac{1}{L}\sum_{t=1}^{L}\operatorname{tr}\{\mathbf{P}_i(t)\} = N, \quad i = 1, \cdots, L \tag{9}$$

$$\mathbf{P}_i(t) \geq 0, \quad t = 1, \cdots, L, \quad i = 1, \cdots, L\,. \tag{10}$$

It can be seen from (8)-(10) that the OPS approach schedules the available transmission power optimally over multiple time slots. When the interference is strong, the OPS approach automatically reduces the number of active SNs at each time slot. Moreover, the scheduled power is adaptive to the strength of interference at each time slot. When $L = 1$, the problem (8)-(10) is equivalent to the problem (5)-(6). That is, the algorithm developed in [2] is only a special case of the proposed OPS approach. Therefore, we expect that the OPS approach has a superior performance than the algorithms proposed in [1] and [2].

In general INR region, it can be seen from (7) that due to the mutual interferences among different links, the mutual information (7) is neither a convex function, nor a concave function of the covariance matrices $\mathbf{P}_i(t), i, t = 1, \cdots, L$. Thus, in general, (8)-(10) is a nonconvex optimization problem.

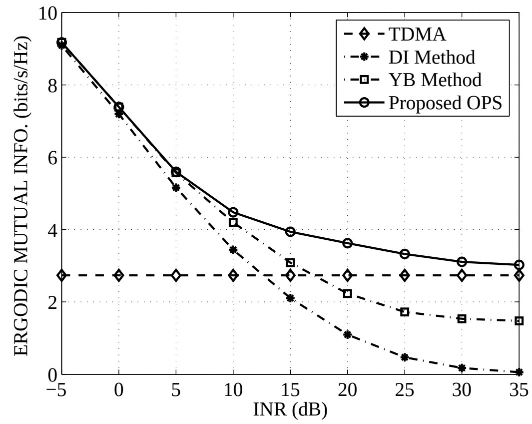

Fig. 1. Ergodic mutual information versus INR.

Since the constraints (9)-(10) are simple linear and matrix positive semidefinite constraints, the projected gradient method can be applied to solve the problem (8)-(10). The details are provided in [3].

To illustrate the potential of the new approach, numerical simulation has been carried out. We simulated a wireless communication network with $L = 6$ simultaneous MIMO links. Each node is equipped with $N = 2$ antennas. we also assume a symmetric transmission environment where $\rho_i = 20$dB, $i = 1, \cdots, 6$, and all $\beta_{i,j}$ are equal. Each simulation point is obtained by averaging over 1000 independent channel realizations.

Fig. 1 shows the ergodic system mutual information versus INR of all methods tested, where the mutual information is normalized over $L = 6$ links. The performance of the TDMA scheme is also shown in Fig. 1 as a benchmark. From Fig. 1 we can see that when the interference is weak, the OPS approach and algorithms in [1], [2] (denoted as DI and YB method in Fig. 1, respectively) have a similar performance. For all methods tested, the mutual information decreases with the increasing INR. When the INR is sufficiently high, the DI and YB methods are even inferior to that of the simple TDMA scheme. However, the proposed OPS approach does not suffer from such a problem. It outperforms all the competing techniques over the whole INR range.

In the journal paper [3], we provide more details.

References

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