Outage Probability for Cooperative Multicarrier MIMO with Statistical Channel Knowledge

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Abstract—In this paper some preliminary studies of power allocation strategy in downlink MIMO cooperative system applied to a multi-carrier cellular system is proposed and evaluated. The system model considers multi-antenna base stations communicating with a couple of single-antenna terminals simultaneously and the system outage probability is evaluated for a given target rate tuple. Besides, optimal power allocation over the carriers is calculated based on knowledge only of the channel statistics at the central station, which is more realistic assumptions and requires only small additional backbone capacity. The results show....

Index Terms—Cooperative MIMO, multicarrier, power allocation, outage Probability, channel statistics

I. INTRODUCTION

Multiple-input multiple-output (MIMO) systems have become one of the most studied topics of the field of wireless communications because of the well-known potential for increasing spectral efficiency when compared to single-antenna systems. However, in high levels of interference scenarios, like in cellular systems, spatial multiplexing MIMO systems can lose much of their effectiveness. Recently, some techniques have been developed in order to reduce intercell interference in MIMO systems and interference reduction based on base station cooperation seems to be a promising one.

When the multiple base stations can fully cooperate, the multicell downlink reduces to a classical MIMO broadcast channel [1] with per-antenna power constraints. In this case, the optimal strategy to maximize the multicell throughput is the joint dirty-paper coding (DPC) [2]. Since practical implementation of DPC is still a problem, some sub-optimal solutions have been proposed and some works can be found in the literature [3], [4], [5].

One of the basic requirements for most of the proposed base station cooperation schemes is the need of perfect channel knowledge at both receivers and network backbone for the joint processing at central station. Therefore, there is a need of a two-step feedback/training from user terminals to each base station and then from base stations to the backbone. In the end, channel knowledge at the backbone is typically imperfect due to delays in feedback link, imperfect training sequence and etc. Besides, the learning channel at the central station requires a great amount of overhead, which is not desired and recommended. In the work presented in [6] the authors provide a comprehensive study of the multicell downlink optimization with limited backbone capacity and they analyze the problem of finding the optimal power allocation and beamforming matrices for different scenarios. Since the statistics are expected to change only in long-term basis, in [7] a power allocation strategy based on the knowledge of channel statistics at the central station, which requires a very small additional backbone capacity, was proposed.

The power allocation minimizing outage probability strategy for single-carrier with partial channel station information at transmitter for a cooperative downlink transmission system was proposed in [7]. However, it was observed that the solution applied for a single-carrier condition cannot be directly applied to the multicarrier case because the gains provided by frequency diversity were inferior to the loss due to the division of power among the carriers [FAZER REFERENCIA A UM REPORT INTERNO OU ALGUM DE REVISTA QUE EST SENDO PREPARADO]. Hence, in this work a power allocation strategy that minimize the outage probability based on the knowledge of channel statistics for a multicarrier system is proposed. The multicarrier power allocation strategy proposed exploits the multiplexing gain of cooperative MIMO and the frequency diversity gain provided by the multicarrier transmission scheme.

This paper is organized as follows. In the next section, the system model is presented. In section ?? we discuss the optimal power allocation under the assumption of perfect channel knowledge and propose the power allocation strategy which minimizes the system outage probability assuming statistical knowledge of the channel. Finally, we conclude the paper with the achieved results and conclusions in sections III and IV, respectively.

II. SYSTEM MODEL

A simple multicell downlink, where two base stations (BS) connected to a central station (CS) communicates simultaneously with two mobile stations, is considered in this work. It is assumed that the base stations are connected to a common backbone via a possibly error-free wired line, which enables some cooperation between base stations. Furthermore, the base stations do not communicate directly to each other. Each BS has two antennas and each terminal has a single one. It is also assumed that each BS knows perfectly the channels while the central station has only the statistical knowledge. Figure 1 illustrates an example of the multicell downlink system.
A similar cooperative multicell downlink scenario was proposed in [4], but a single-carrier transmission was assumed. This work aims at extending such model for the Orthogonal Frequency Division Multiplexing (OFDM) multicarrier transmission scheme. For each carrier, the channels between BS and MS are assumed to be a frequency flat fading channels with \( h_{bk}[n] \sim \mathcal{N}(0, \sigma^2_{bk}) \). For an OFDM system with \( N \) carriers, the base station \( b \) forms its transmit vector at the \( n \)-th carrier as follows:

\[
x_b[n] = g_{b1}[n]s_{b1}[n] + g_{b2}[n]s_{b2}[n],
\]

where \( [g_{b1}[n], g_{b2}[n]] \) and \( s[n] = [s_{b1}[n], s_{b2}[n]]^T \) are the \( M \times 2 \) precoding matrix and the message vector, respectively. The latter is subject to the power constraint \( \sum_n p_{bk}[n] \leq P_b \), where \( P_b \) is maximum transmission power. Adopting zero-forcing beamforming as the precoding scheme, the received signal of the \( k \)-th user terminal at the \( n \)-th carrier is given by

\[
y_k[n] = a_{1k}[n]s_{1k}[n] + a_{2k}[n]s_{2k}[n] + n_k[n],
\]

where \( a_{bk}[n] = h_{bk}^H[n]g_{bk}[n] \) represents the channel gain between base station \( b \) and terminal \( k \) at carrier \( n \). The unitary precoding vector \( g_{bk}[n] \) is orthogonal to \( h_{bj}[n] \) for \( j \neq k \) and the random variable \( |a_{bk}[n]|^2 \) has a chi-square distribution with \( 2(M-1) \) degree of freedom. In this situation, the rate achieved by the \( k \)-th terminal can be expressed as:

\[
R_k = \frac{1}{N} \sum_{n=1}^{N} R_k[n]
\]

where \( R_k[n] = \log(1 + |a_{1k}[n]|^2 p_{1k}[n] + |a_{2k}[n]|^2 p_{2k}[n]) \).

The objective is to optimize the power allocation over the carriers in order to minimize the outage probability assuming that the central station has knowledge only of the channel statistics. For a given the target rate tuple \( \gamma \), the optimal power allocation is the solution of the following optimization problem:

\[
\begin{align*}
\text{minimize} & \quad P_{\text{out}}(\gamma) = 1 - \prod_{k=1}^{2} \Pr (R_k > \gamma_k) \\
\text{subject to } & \quad \sum_k \sum_n p_{bk}[n] \leq P_b.
\end{align*}
\]

Initial studies demonstrated that, when \( N \geq 2 \) and considering the statistical channel knowledge, a closed-form for the outage probability can result in a complex and a numerical ill conditioned solution. Besides, other problems were identified when simulations done in a multicarrier scenario.

The outage probability for different values of SNR and carriers, when the target rate tuple is \( \gamma = [1, 1] \) (bits per channel use) and the both links have the same noise power, is presented in the Figure 2. It is observed that the optimal strategy sometimes consists of allocating only a few carriers, even when more carriers are available. Hence, depending on SNR values, the distribution of power among carriers can result in rate reduction and increased outage probability of the system. Besides, frequency diversity gain only can be explored after a certain SNR value which is dependent of the number of carriers considered.

![Fig. 2. Outage probability as a function of SNR](image.png)
III. RESULTS

The results will be presented in terms of the optimal values of $\theta_1$ and $\theta_2$ (blue curves) and the optimal number of allocated carriers $N_{\text{opt}}$ (red curves). The optimal values of $\theta_b$ and $N_{\text{opt}}$, for the scenario where the target rate tuple is $\gamma = [1, 1]$ (bits per channel use) and when the both links have the same noise power, are presented in the Figure 3. As expected, $\theta_1$ and $\theta_2$ have the same values since the channel conditions and target rates are the same. Besides, as already observed, in order to minimize the outage probability, the optimal number of allocated carriers $N_{\text{opt}}$ was found and it is greater than 1 only when SNR is above a certain value (around 9 dB in these simulations). Hence, in this scenario, both terminals are allocated with equal power and the system outage is minimized only for the optimal number of allocated carriers.

On the other hand, when the target rate tuple is different for each terminal ($\gamma = [1, 3]$), more power is allocated to the terminal with the highest target rate in order to minimize the outage probability (see Figure 4). However, this power difference only happens when SNR is greater than a certain value. In this scenario, the minimum system outage is only achieved with one allocated carrier, more carriers are allocated only when SNR values are greater than 19dB.

Finally, Figure 5 presents the results for the scenario where noise power of the links is different (asymmetric links). The noise power between is modeled as follows: $\sigma_{ii} = \alpha \sigma_{ij}$ for $\alpha < 1$, $i, j = 1, 2$ and $i \neq j$. Considering $\alpha = 0.5$, it is possible to see that the algorithm allocates more power to the links which are in better conditions. This fact is observed specially for intermediate values of SNR; in high SNR region the allocation approximates to the equal power allocation because the difference of performance of the links decreases as the total available power increases.

IV. CONCLUSIONS

It was proposed an algorithm to perform the power allocation in cooperative MIMO systems with multiple carriers. Earlier, we observed that the solution found in single-carrier case cannot be directed applied to the multicarrier case because the gains provided by frequency diversity were inferior to the loss due to the division of power between carriers. The proposed algorithm exploits this trade off and minimizes the outage probability of the system.

V. ACKNOWLEDGMENT

This work is partially supported by CNPq (Brazil) under grants WIPA(554047/2006-3) and QUASAR(553207/2005-9) projects.

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Fig. 5. Optimal values of $\theta_1$, $\theta_2$ and $N_{\text{opt}}$ with asymmetric links


