A LOW-COMPLEX SDMA GROUPING STRATEGY FOR THE DOWNLINK OF MULTI-USER MIMO SYSTEMS

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ABSTRACT

In this work, a sub-optimal Space Division Multiple Access (SDMA) grouping algorithm is proposed for the downlink of Multi-User MIMO systems. It uses a new Spatial Compatibility Check metric to estimate the grouping efficiency without needing to compute MIMO filter weights, thus reducing the complexity of SDMA grouping. Moreover, an iterative variant of the Block Diagonalization for Throughput Maximization algorithm [1] is employed to select the number of streams allocated to each user and to maximize the sum capacity of the SDMA group. The proposed SDMA strategy is compared through simulation with Single-User, Random Grouping, and Exhaustive Search, and it is shown to have a good performance-complexity trade-off.

I. INTRODUCTION

Multiple-Input-Multiple-Output (MIMO) techniques are a promising solution for high throughput provision in 4G systems [2]. In the downlink of Multi-User MIMO (MU-MIMO) systems, if Channel State Information (CSI) is available, Mobile Stations (MSs) can be multiplexed in space, e.g., with a transmit Zero Forcing (ZF) filter [3, 4], while reusing the same resource in frequency and time. A group of such MSs is termed a Space Division Multiple Access (SDMA) group.

If MSs' spatial channels are close to orthogonal, spatial multiplexing gains are obtained by placing MSs in the same SDMA group. Otherwise placing them in the same group may lead to unacceptable performance. In this case, different resources, e.g., different Time-Slots (TSs), should be assigned to the groups, which reduces spectral efficiency. Thus, to improve spectral efficiency, it is important to place MSs in SDMA groups based on their channel properties avoiding MSs with correlated channels in the same group.

The problem of finding the best SDMA group is similar to the well-known knapsack problem and is a Non-Polynomial-Complete combinatorial problem [5, 6]. Then, the optimum group can be found with probability one through an exhaustive search. Since performance, e.g., in terms of capacity, average Signal-to-Noise Ratio (SNR), or average Bit Error Rate, depends on the used MIMO technique and on the channels of all MSs in the group, the MIMO filter weights must be computed for each candidate group. Thus, an exhaustive search becomes too complex, even for a moderate number of MSs, and heuristic strategies able to find an efficient grouping with acceptable complexity are preferred. In fact, if the grouping efficiency, i.e., the spatial compatibility among the MSs in the group, can be sub-optimally estimated through a simple Spatial Compatibility Check (SCC) without needing to compute MIMO filter weights, substantial computational costs can be saved.

In this work, a sub-optimal SDMA grouping algorithm is proposed for the downlink of Multi-User MIMO systems. It uses a new SCC metric, proposed here, which does not depend on the MIMO filter weights, thus reducing the complexity of SDMA grouping. Moreover, an iterative variant of the Block Diagonalization for Throughput Maximization algorithm [1] is employed to select the number of data streams allocated to each MS and to maximize the sum capacity of the SDMA group. The performance of the proposed scheme is then evaluated through simulations.

In Section II, the adopted system model is described and the BDTM algorithm [1] is shortly reviewed. In Section III, some SDMA grouping strategies and their SCC metrics are briefly revisited. Then, the proposed SCC metric and SDMA grouping algorithm proposed here are introduced. In Section IV, parameter values and simulation results are discussed. Finally, in Section V, some conclusions on the conducted investigations are drawn.

II. SYSTEM MODEL

This work focuses on the downlink of a MU-MIMO system with one tri-sectored Base Station (BS) and K active MSs per sector. Each BS sector has a Uniform Linear Array (ULA) of antennas with n_T elements. Each MS g has a ULA with n_{Rg} elements. Per sector, a single frequency channel is considered, which is simultaneously used by all the MSs in an SDMA group. The channel response is assumed flat and perfect CSI is considered. This scenario could be seen as one subcarrier of an OFDM-based system with Time Division Duplexing (TDD) and perfect channel estimation on which SDMA is applied.

Consider an SDMA group $\mathcal{G}$ with G MSs. Let $n_R = \sum n_{Rg}$, $g = 1, \dots, G$, denote the total number of receiving antennas in the group, $(\cdot)^T$ denote vector or matrix transposition, and $\mathrm{blockdiag}\{\cdot\}$ denote a block diagonal matrix whose diagonal blocks are given as arguments.

The BS sector transmits the data symbols, which are organized in the input data vector $\mathbf{d}_\mathcal{G} \in \mathbb{C}^{n_R \times 1}$, to the MSs in the group $\mathcal{G}$. This vector is modulated using the modulation matrix $\mathbf{M}_\mathcal{G} \in \mathbb{C}^{n_T \times n_R}$, transmitted through the chan-

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nel $\mathbf{H}_\mathcal{G} \in \mathbb{C}^{n_R \times n_T}$, and distorted by noise, represented by $\mathbf{n}_\mathcal{G} \in \mathbb{C}^{n_R \times 1}$. The received signal is demodulated using the demodulation matrix $\mathbf{D}_\mathcal{G} \in \mathbb{C}^{n_R \times n_R}$ producing at the receivers the estimated output data vector

$$\hat{\mathbf{d}}_\mathcal{G} = \mathbf{D}_\mathcal{G}(\mathbf{H}_\mathcal{G}\mathbf{M}_\mathcal{G}\mathbf{d}_\mathcal{G} + \mathbf{n}_\mathcal{G}) \in \mathbb{C}^{n_R \times 1} \quad (1a)$$

$$\hat{\mathbf{d}}_\mathcal{G} = \begin{bmatrix}\hat{\mathbf{d}}_1^T & \dots & \hat{\mathbf{d}}_G^T\end{bmatrix}^T, \; \mathbf{d}_\mathcal{G} = \begin{bmatrix}\mathbf{d}_1^T & \dots & \mathbf{d}_G^T\end{bmatrix}^T$$

$$\mathbf{M}_\mathcal{G} = \begin{bmatrix}\mathbf{M}_1 & \dots & \mathbf{M}_G\end{bmatrix} \quad (1b)$$

$$\mathbf{D}_\mathcal{G} = \mathrm{blockdiag}\{\mathbf{D}_1, \dots, \mathbf{D}_G\} \quad (1c)$$

$$\mathbf{H}_\mathcal{G} = \begin{bmatrix}\mathbf{H}_1^T & \dots & \mathbf{H}_G^T\end{bmatrix}^T \quad (1d)$$

$$\mathbf{n}_\mathcal{G} = \begin{bmatrix}\mathbf{n}_1^T & \dots & \mathbf{n}_G^T\end{bmatrix}^T$$

of the transmitted data symbols. The data symbols are assumed to be uncorrelated and to have unit power. The noise is considered to be spatially white with average power σ_n^2. The model in (1) encompasses the signals of all the MSs in the group. Since the demodulation process is distributed among the MSs, $\mathbf{D}_\mathcal{G}$ has a block diagonal structure.

The matrices $\mathbf{M}_g$ in (1b) and $\mathbf{D}_g$ in (1c) are defined according to the MIMO technique used. In [1], Block Diagonalization (BD) algorithms are proposed for the downlink of MU-MIMO systems. It is a generalization of the ZF filter for MSs with multiple antennas, forcing the signal of one MS to lie on the null space of all other MSs' channels, i.e., $\mathbf{H}_i\mathbf{M}_j = \mathbf{0}, \forall i \neq j$, and has been shown to outperform the ZF filter. Next, the BDTM algorithm [1] is reviewed.

From (1d), a matrix $\tilde{\mathbf{H}}_g$ containing the channels of all other MSs than the MS g is defined, i.e.,

$$\tilde{\mathbf{H}}_g = \begin{bmatrix}\mathbf{H}_1^T & \dots & \mathbf{H}_{g-1}^T & \mathbf{H}_{g+1}^T & \dots & \mathbf{H}_G^T\end{bmatrix}^T. \quad (2)$$

From the Singular Value Decomposition (SVD) of $\tilde{\mathbf{H}}_g$, with rank $\tilde{L}_g = \mathrm{rank}\{\tilde{\mathbf{H}}_g\} \leq n_R - n_{Rg}$,

$$\tilde{\mathbf{H}}_g = \tilde{\mathbf{U}}_g\tilde{\mathbf{\Lambda}}_g^{1/2}[\tilde{\mathbf{V}}_g^{(1)}\,\tilde{\mathbf{V}}_g^{(0)}]^H, \quad (3)$$

the last $n_T - \tilde{L}_g$ right singular vectors of $\tilde{\mathbf{H}}_g$ organized in $\tilde{\mathbf{V}}_g^{(0)}$ build a basis for the null space of $\tilde{\mathbf{H}}_g$. The channel of the MS g is then projected on the null space of all other MSs' channels by post multiplying $\mathbf{H}_g$ with $\tilde{\mathbf{V}}_g^{(0)}$. From the SVD of $\mathbf{H}_g\tilde{\mathbf{V}}_g^{(0)}$, with rank $L_g = \mathrm{rank}\{\mathbf{H}_g\} \leq n_{Rg}$,

$$\mathbf{H}_g\tilde{\mathbf{V}}_g^{(0)} = \mathbf{U}_g\mathbf{\Lambda}_g^{1/2}[\mathbf{V}_g^{(1)}\,\mathbf{V}_g^{(0)}], \quad (4)$$

the first L_g right singular vectors of $\mathbf{H}_g\tilde{\mathbf{V}}_g^{(0)}$ organized in $\mathbf{V}_g^{(1)}$ build a basis for the equivalent channel, which was projected on the null space of $\tilde{\mathbf{H}}_g$.

Then, the demodulation and modulation matrices of MS g are defined, respectively, as

$$\mathbf{D}_g = \mathbf{U}_g^H, \qquad \mathbf{M}_g = \tilde{\mathbf{V}}_g^{(0)}\mathbf{V}_g^{(1)}\mathbf{\Gamma}_g^{1/2} \quad (5)$$

where the diagonal power loading matrix $\mathbf{\Gamma}_g^{1/2}$ is obtained for each MS g after applying the Water Filling (WF) algorithm on the eigenvalues of all MSs together, i.e., on the diagonal elements of

$$\mathbf{\Lambda}_\mathcal{G} = \mathrm{blockdiag}\{\mathbf{\Lambda}_1, \dots, \mathbf{\Lambda}_G\}, \quad (6)$$

concluding the BDTM algorithm.

Let $(\cdot)^H$ denotes the conjugate transpose of a matrix and $\mathbf{I}$ an identity matrix of suitable dimension. Then, using (1) and (5), the channel capacity of MS g and of group $\mathcal{G}$ are given, respectively, by

$$\begin{aligned} C_g &= \log_2\left[\det\left[\mathbf{I} + \sigma_n^{-2}\mathbf{D}_g\mathbf{H}_g\mathbf{M}_g\mathbf{M}_g^H\mathbf{H}_g^H\mathbf{D}_g^H\right]\right] \\ C_\mathcal{G} &= \log_2\left[\det\left[\mathbf{I} + \sigma_n^{-2}\mathbf{D}_\mathcal{G}\mathbf{H}_\mathcal{G}\mathbf{M}_\mathcal{G}\mathbf{M}_\mathcal{G}^H\mathbf{H}_\mathcal{G}^H\mathbf{D}_\mathcal{G}^H\right]\right]. \end{aligned} \quad (7)$$

III. SDMA IN THE MU-MIMO DOWNLINK

To avoid an exhaustive search, many sub-optimal SDMA grouping strategies were proposed in the literature, e.g., [5–9]. In Sections III-A and III-B, some existing SDMA algorithms and their SCC metrics are shortly discussed. In Section III-C, the new SCC metric proposed here is presented. In Section III-D, the new SDMA grouping strategy proposed in this paper is described.

A. SDMA grouping strategies: state of the art.

In [5], various SDMA algorithms are proposed for the downlink of a TDD system with a multi-antenna BS and single-antenna MSs. Therein, the SCC requires the Signal-to-Interference plus Noise Ratio (SINR) of every MS in an SDMA group to be above a minimum threshold. Different SDMA groups are multiplexed in the TSs of a Time Division Multiple Access (TDMA) frame.

Two strategies from [5] are of interest here: the First Fit (FF) and the Best Fit (BF). Assuming K active MSs associated with the BS, the FF strategy assigns the first MS to the first TS of a TDMA frame. Then, the next unassigned MS is tested for compatibility in the current TS. If it fulfills the SCC, it is added to the current TS, which is then shared through SDMA. Otherwise, the next MS is tested. This process continues until compatible MSs are no longer found. Then, the procedure is repeated in the next TS, when a new SDMA group is built, and continues until the whole TDMA frame is allocated or all MSs are assigned. The BF strategy works similarly. The only difference lies on the fact that with BF every MS is tested for compatibility in the current TS, but is not immediately added to the SDMA group if it passes the SCC. Instead of this, all MSs are tested and the most compatible MS is added first to the group. Then, the procedure is repeated with the remaining MSs. The BF strategy is more complex than the FF one, but it provides better results for a larger number of MSs. Per TS at most K and $(1 + \sum(K - i))\,, i = 1, \dots, \min\{K - 1, n_T - 1\}$, SCCs are required for the FF and BF schemes, respectively.

In [8], BD is used to separate the MSs in space while a tree structure is used to avoid an exhaustive search for the best grouping. With $L = K$ active MSs and $\sum n_{Ri} \leq n_T, i = 1, \dots, L$, the tree contains L levels indexed by l, each containing l SDMA groups. Level $l = 1$ contains 1 SDMA group with L MSs and Level $l = L$ contains L groups with 1 MS each. The tree can be built from the bottom to top by merging the most compatible two groups of the inferior level. Then, to build the tree,

$\left(1+\sum\binom{l}{2}\right)$, $l=2,\ldots,L$, SCCs are required. In [8], the average SNR or average capacity of the group are used as SCC metric. The level $l^\star$ with the best trade-off between the number of required TSs (number of SDMA groups) and the sum capacity or average SNR of all groups in the level is kept as the optimum level. Its SDMA groups are then multiplexed in time.

In [9], BD with coordinated transmit-receive processing [1] is used in an SDMA scheme which schedules for transmission the channels with highest eigenvalues. Therein, however, no SCC is directly performed and only the channel energy is taken into account. Therein, one SVD is required for each of the K MSs.

In [10], the complexity of the SDMA grouping is limited by setting minimum and maximum group sizes, q_{min} and q_{max}, when searching for the best group. To avoid computing MIMO filter weights for all candidate groups, a two step procedure is used: first, an SCC is performed for each two MSs' channels, i.e., $\binom{K}{2}$ SCC calculations are done. Then, it is searched for the group that minimizes the sum of the SCC metric for all pairs of MSs in the group. For a search on a stream basis instead of on an MS basis, the scheme in [10] relies on the SVD of MSs' channels.

B. Spatial Compatibility Check:state of the art.

Except for [10] working on an MS basis, the mentioned strategies have complex SCCs which depend on the MIMO filter weights [5, 8] or on a channel decomposition [9]. Instead of this, a low-complex and efficient SCC is desirable. A well-known and low-complex measure of the correlation among two vector channels $\mathbf{h}_i$ and $\mathbf{h}_j$ is its normalized scalar product

$$\rho_{ij} = \left|\mathbf{h}_i\mathbf{h}_j^H\right| / \left\|\mathbf{h}_i\right\| \left\|\mathbf{h}_j\right\| \tag{8}$$

where $|\cdot|$ and $\|\cdot\|$ are the modulus of a complex scalar and the Euclidean norm of a complex vector, respectively. The metric in (8) has been often used for SCC [5–7], however, as discussed in [10], it does not reduce to a single value when there are multiple antennas. For two MIMO channels, a related metric, which reduces to a single value, is the minimum angle between two subspaces [7]. However, according to [10], it did not perform so well as the normalized Frobenius norm they proposed

$$\xi_{ij} = \left\|\mathbf{H}_i\mathbf{H}_j^H\right\|_F^2 / \left(n_{R_i} n_{R_j}\right) \tag{9}$$

where $\|\cdot\|_F$ is the Frobenius norm of a matrix, and n_{Ri} and n_{Rj} are the number of antennas of MS i and j, respectively. ξ_{ij} is an estimate of the overall correlation among the two MIMO channels. Since it deals with two channels at a time, it is used in [10] as part of a Compatibility Optimization Algorithm (COA) which looks for the group with minimum sum of (9), as mentioned in the Section III-A.

Provide a precise estimation of the complexity of each mentioned strategy is a difficult task. Thus, just a rough estimation of the number of SCCs per TS is summarized in Table 1, with their respective requirements.

Table 1: Estimated # of SCCs/TS of the SDMA strategies.

SDMA grouping	**SCC depends on**	**# of SCCs / TS**
FF [5]	SINR, MIMO weights	K
BF [5]	SINR, MIMO weights	$1+\sum(K-i)$
Tree-based [8]	SNR, C, MIMO weights	$1+\sum\binom{l}{2}$
Max. eigenv. [9]	SVD	K
COA [10]	ξ_{ij} (for stream-based: SVD)	$\binom{K}{2}$

C. Proposed Spatial Compatibility Check metric

For the considered scenario, a suitable SCC metric should be low-complex and deal with groups of arbitrary size. It should also capture the average correlation among all the channels in the group $\mathcal{G}$. From the ideas of ρ_{ij} in (8) and ξ_{ij} in (9), a matrix $\mathbf{R}$ with the correlations among all channels in $\mathcal{G}$ can be built. Let $[\cdot]_i$ denote the i^{th} row of a matrix. Then, $\mathbf{R}$ is written as

$$\begin{aligned}&\mathbf{R} = \mathbf{N}\mathbf{H}_\mathcal{G}\mathbf{H}_\mathcal{G}^H\mathbf{N} - \mathbf{I}\\ &\mathbf{N} = \operatorname{diag}\left\{\left\|[\mathbf{H}_\mathcal{G}]_1\right\|^{-1}, \ldots, \left\|[\mathbf{H}_\mathcal{G}]_{n_R}\right\|^{-1}\right\}\end{aligned} \tag{10}$$

where $\operatorname{diag}\{\cdot\}$ is a diagonal matrix with diagonal elements given as arguments.

To increase capacity, when comparing groups the SCC metric should fairly favor larger groups whose channels' energy is high. Moreover, for groups with similar channel energy and correlation characteristics, the group with more uniform channel energy distribution is desired. Following these guidelines and using (10), the following heuristic SCC metric, $\rho_\mathcal{G}$, is proposed here:

$$\rho_\mathcal{G} = \frac{\mu_\mathcal{G} n_R}{\|\mathbf{R}\|_F}, \quad \mu_\mathcal{G} = \left(\prod_{i=1}^{n_R} \left\|[\mathbf{H}_\mathcal{G}]_i\right\|\right)^{\frac{1}{n_R}}, \tag{11}$$

where the Frobenius norm of $\mathbf{R}$ captures correlation effects while the factor n_R and the geometric mean $\mu_\mathcal{G}$ favor larger groups and high/uniform channels' energy distribution, respectively. The proposed metric is clearly less complex than most of the SCC metrics in Sections III-A and III-B.

D. Proposed grouping algorithm

Here an SDMA grouping strategy inspired on the FF and BF strategies (see Section III-A) is proposed. In [5], an MS cannot be allocated to multiple TSs in a same frame, i.e., traffic priority handling within a TDMA frame is not considered. Thus, multi-user diversity gains are eventually reduced because a smaller set of MSs is considered for each subsequent TS in a frame.

As a first step of the algorithm proposed here, the MS with highest priority is selected and assigned to the current TS, thus building a one-MS SDMA group. As a second step, compatible MSs are searched according to the FF or BF strategy from [5]. Differently from [5], the proposed low-complex SCC metric $\rho_\mathcal{G}$ from (11) is used to check which MSs are compatible. For the FF strategy, an MS is selected among the $(K-1)$ remaining MSs and is added temporarily to the TS (SDMA group). The SCC metric $\rho_\mathcal{G}$

is calculated for this extended group and compared with that of the original group. If $\rho_{\mathcal{G}}$ decreased, the temporarily added MS is rejected, removed from the SDMA group, and the next one is tested. Otherwise, it is added permanently to the group. The same applies to the BF scheme. However, with BF all MSs are tested and the one that most increases $\rho_{\mathcal{G}}$ is added first to the group. The second step is repeated with the updated SDMA group until a maximum group size G_{max} is reached, or until compatible MSs are no longer found. Once the final group is known, the MIMO filter weights are computed for it. Then, MSs' priorities are updated and the whole procedure is repeated for the next TS.

Note that, differently from [5], the proposed strategy assumes that MSs can be allocated to multiple TSs in a frame. Thus, multi-user diversity and spatial multiplexing gains can be obtained, since the complete set of active MSs is considered for SCC in each TS. Moreover, better Quality of Service (QoS) control is possible since MSs with higher priority can use multiple TSs within a frame. The complexity increase due to a larger MS set is compensated by the low-complex SCC metric, since $\rho_{\mathcal{G}}$ requires to compute neither MIMO filter weights nor channel capacity formulas at each step. Indeed, complexity can be reduced even more by efficiently storing and reusing previously computed parts of $\rho_{\mathcal{G}}$. Per TS, at most K and $(1 + \sum(K-i))\,, i = 1, \ldots, \min\{K-1, G_{max}-1\}$, SCCs are required for the FF and BF strategies, respectively, as for FF and BF in Table 1.

Differently from [8], the BDTM algorithm [1] (see Section II) is used here, which is applied to the final group generated by the procedure above. Due to the WF algorithm, some channels may get no power and, therefore, orthogonalization with respect to them does not improve the channel capacity. Then, the following iteration is proposed and applied to $\mathbf{H}_{\mathcal{G}}$ in order to remove those channels and increase capacity:

i. Apply the BDTM algorithm to the channel matrix $\mathbf{H}_{\mathcal{G}}$.
ii. While $\{\exists i \in [1, n_R] \,|\, \gamma_i = 0\}$, where γ_i is the power allocated to the i^{th} vector channel in $\mathbf{H}_{\mathcal{G}}$:
   a. remove the c^{th} row of $\mathbf{H}_{\mathcal{G}}$, where $c = \arg\min_{c}\{\lambda_c\}$, and λ_c is the c^{th} eigenvalue in $\mathbf{\Lambda}_{\mathcal{G}}$,
   b. apply the BDTM algorithm to the new matrix $\mathbf{H}_{\mathcal{G}}$.

Note that after removing one vector channel c, only the matrices $\mathbf{M}_g$ and $\mathbf{D}_g$ of the MSs whose MIMO channels have not changed must be fully recomputed. $\mathbf{M}_g$ and $\mathbf{D}_g$ of the MS which has lost one channel dimension are obtained by adequately removing one of its columns/rows and adjusting the allocated power. Since the SCC is highly simplified, this additional complexity is justified.

IV. SIMULATION RESULTS

A single-cell system with a tri-sectored BS and 1/3 frequency reuse is assumed in the simulations. Each sector is equipped with a ULA with $n_T = 8$ antenna elements. A total number of $K = 10$ active MSs are randomly placed in each sector. Each MS has a ULA with $n_R = 2$ elements. ULA elements are separated by half wavelength. An average SNR of 10 dB is considered in the system. Round Robin scheduling, full-buffer traffic model, a maximum group size $G_{max} = 4$, and a TS of 2 ms are assumed. The proposed scheme is applied on a TS basis.

MSs' channel matrices $\mathbf{H}_k$ are obtained using

$$\mathbf{H}_k = \sqrt{K_R/(1+K_R)}\overline{\mathbf{H}} + \sqrt{1/(1+K_R)}\mathbf{H}_w \quad (12)$$

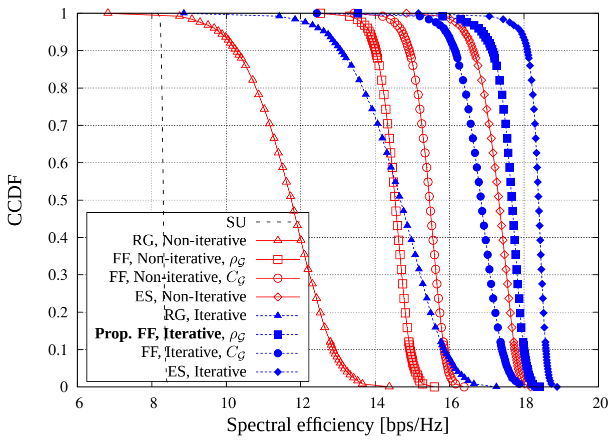
where K_R is the Rice factor, and $\overline{\mathbf{H}}$ and $\mathbf{H}_w$ are the Line-Of-Sight (LOS) and Non-LOS (NLOS) channel components, respectively [11, 12]. Differently from [8–10], time-correlation is considered in the channel model, i.e., the channel coefficients in the NLOS component of (12) come from independent (antennas are uncorrelated) time-correlated Rayleigh processes. A center frequency of 3.5 GHz and a speed of 10 km/h for the MSs are assumed, thus characterizing the rate of change of the channel in time. A Rice factor $K_R = 10$ dB in (12) is assumed. MSs' channels become relatively correlated if the angular separation among the MSs is small. The BS power is allocated to the MSs according to the iterative BDTM.

In Fig. 1, the Complementary Cumulative Distribution Function (CCDF) of the spectral efficiency of the system is shown for the proposed SDMA grouping scheme with FF, indicated as **Prop. FF**, and with BF, indicated as **Prop. BF**. Results considering the proposed SCC metric, $\rho_{\mathcal{G}}$, given by (11), and the group capacity, $C_{\mathcal{G}}$, given by (7), are presented for comparison. Morever, results for the non-iterative BDTM [1] are also included to illustrate the gains of the iterative BDTM algorithm suggested here. The proposed schemes, **Prop. FF** and **Prop. BF**, are compared with: Single-User (SU) grouping, in which the highest-priority MS transmits alone; Random Grouping (RG), in which the highest-priority MS transmits together with other $(G_{max}-1)$ randomly selected MSs; and Exhaustive Search (ES) grouping, in which the group with highest capacity and containing the highest-priority MS is scheduled.

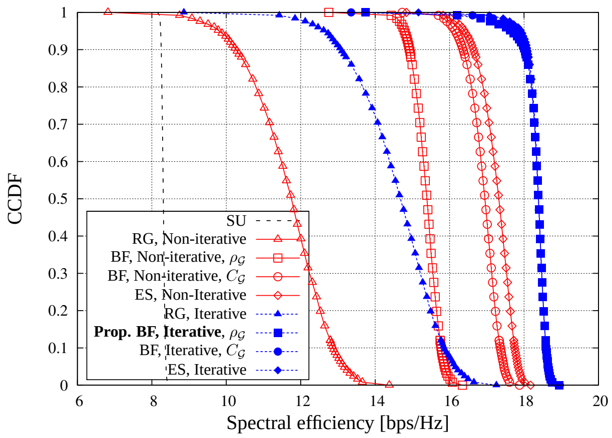
It can be noted in Fig. 1 that the proposed schemes, **Prop. FF** and **Prop. BF**, outperform the SU and RG strategies in all the cases. It can also be noted that the iterative BDTM (filled symbols) provides considerable capacity gains compared to the non-iterative BDTM (hollow symbols).

For the non-iterative BDTM, it can be seen in Fig. 1(a) that the application of the proposed SCC metric $\rho_{\mathcal{G}}$ does not reduce considerably the performance of the FF grouping when compared to the use of the group capacity $C_{\mathcal{G}}$ as SCC metric. Therein, a loss of ≈ 6% in the 10% outage capacity is verified. Thus, complexity can be substantially reduced using $\rho_{\mathcal{G}}$ in the SCC with only a small capacity loss.

With the iterative BDTM, the performance of the proposed scheme with FF is even better when applying $\rho_{\mathcal{G}}$ than using $C_{\mathcal{G}}$ as SCC metric. That inversion in the trend of the curves is due to the fact that the FF strategy using $C_{\mathcal{G}}$ as SCC metric will admit a new MS in the SDMA



(a) First Fit strategy.



(b) Best Fit strategy.

Figure 1: Performance of the proposed schemes: **Prop. FF**, **Prop. BF**.

group whenever the group capacity increases. Moreover, with the iterative BDTM, the remotion of MS channels which received zero power affects group capacity, but is ignored by $\rho_{\mathcal{G}}$ since MIMO filter weights calculation, and consequently channel remotion, is performed only for the final group built. This leads to potentially different SDMA groups when using $C_{\mathcal{G}}$ and $\rho_{\mathcal{G}}$ as SCC metrics. Since $\rho_{\mathcal{G}}$ favors larger groups with high energy and captures the correlations among the channels, its performance is $\approx$ 6% higher in terms of the 10% outage capacity.

The proposed scheme with BF is obviously better than that with FF, since all MSs are submitted to the SCC with the best being added to the SDMA group. In Fig. 1(b), it can be seen that the difference in terms of the 10% outage capacity considering $\rho_{\mathcal{G}}$ and $C_{\mathcal{G}}$ is only of $\approx$ 8.8% in the non-iterative BDTM case. For the proposed scheme, which uses the iterative BDTM, this difference is negligible. Indeed, note that the curves of proposed scheme with BF, **Prop. BF**, and of ES curves even overlap each other.

The complexity-performance trade-off is particularly attractive when employing the proposed scheme with BF, **Prop. BF**, which uses $\rho_{\mathcal{G}}$ as SCC metric and applies the iterative BDTM. In this case, gains of 37.7% and 118% in the 10% outage capacity are obtained with respect to the RG and SU cases, respectively. Note that the BF strategy is still less complex than evaluating all SDMA groups of sizes $G_{max} = 4$, whenever $K > 6$, since $\binom{K}{G_{max}} > (1 + \sum(K-i)), i = 1, \ldots, \min\{K-1, G_{max}-1\}$. Moreover, MIMO filter weights are computed only for the final group built. Nevertheless, the proposed scheme with FF, **Prop. FF**, can be used for even lower complexity.

V. Conclusions

In this paper, a new SDMA grouping algorithm and a new metric to perform a Spatial Compatibility Check among the MSs are investigated. The performance of the proposed scheme is evaluated and compared with that of Single-User, Random Grouping, and Exhaustive Search cases. It is pointed out that the proposed SCC metric allows to considerably reduce complexity with only small or no performance losses. The proposed scheme provided capacity gains of more than 30% and 100% with respect to the RG and SU performance, respectively, and approximated the performance of the ES case.

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