XXXVII SIMPÓSIO BRASILEIRO DE TELECOMUNICAÇÕES E PROCESSAMENTO DE SINAIS - SBrT2019, 29/09/2019–02/10/2019, PETRÓPOLIS, RJ

SDMA Grouping for 5G Systems

Francisco Hugo Costa Neto and Tarcisio Ferreira Maciel

***Abstract*— In this study, we investigate the problem of maximization of the total data rate of a multi-user multiple input multiple output (MU-MIMO) system. We evaluate a solution to the space-division multiple access (SDMA) grouping problem that is composed of two parts. In the first part, we partition mobile stations (MSs) into clusters of spatially correlated MSs. In the second part, we schedule MSs from different clusters to build an SDMA group so that the multi-user (MU) interference is minimized. Looking for an implementation with reduced hardware cost, we employ a hybrid beamforming scheme and analyze its impact in terms of total data rate. The analog precoder is based on the channel information obtained from clustering while different digital precoding components are considered, namely zero-forcing (ZF) and maximum ratio transmission (MRT). The simulation results indicate that the combination of a proper partition of MSs into clusters and the suitable scheduling of MSs provides a technique able to exploit spatial compatibility more effectively and reduces inter-cell interference. Moreover, when the ZF is considered as digital precoding scheme, there is an increase of the total data rate.**

***Keywords*— SDMA grouping, hybrid beamforming, multi-user MIMO**

I. Introduction

The 5th generation (5G) of wireless communications imposes huge requirements on the efficiency and quality of the offered services and involves serious concerns about how to satisfy them. Moreover, the exponential growth of data rates and massive device connectivity contradicts the unavoidable spectrum shortage [1].

Several technologies have been developed in order to exploit the radio resources (e.g., space, time and frequency) as to support simultaneous transmission of independent data streams, so that higher rates and improved quality of service (QoS) can be achieved. The performance of such technologies depends on the channel characteristics of the selected MS and on how efficiently the interference is mitigated [2].

In the downlink (DL) of a multiple input multiple output (MIMO)-orthogonal frequency division multiple access (OFDMA) system, the base station (BS) determines which resources to allocate to which MS and sends data to the selected MS on the allocated resources. SDMA can be used to group a set of spatially separable MSs, namely, an SDMA group, to share radio resources. Moreover, SDMA groups must contain spatially compatible MSs to improve capacity, otherwise, the signals sent to the MSs may interfere with each other and threaten the system performance. Therefore, the SDMA group composition impacts the system operation efficiency [3].

SDMA-OFDMA systems can allocate resources in time, frequency and space dimensions to different MSs. In this context, the large number of degrees of freedom leads to highly complex radio resource allocation (RRA) problems [3], [4]. In particular, SDMA grouping can be classified as an integer optimization problem, since it involves integer variables, like the number of MSs or of time-frequency resource blocks. Usually, these problems have combinatorial behavior, which implies high complexity and ask for an exhaustive search in order to obtain an optimal solution [3]. Aiming to reduce complexity, the RRA problem can be divided into subproblems (e.g., frequency assignment, power allocation, SDMA grouping, etc.), each considering separately a different dimension of the problem. Even though, the resulting subproblems still hold a considerably high level of complexity, so that suboptimal strategies are often proposed in the literature to solve them [4].

In particular, for the SDMA grouping problem, two methodologies stand out: i) iterative SDMA grouping; and ii) clustering followed by MS scheduling. In [3], [5], there is a direct iterative formation of groups, i.e., each MS is included sequentially in the group, according to the spatial compatibility between the candidate MS and the MSs already admitted to the SDMA group. Another approach, used in [6], [7], first clusters all MSs of the system with spatially correlated channels and afterwards schedules MS from different clusters on a same resource. In [8], the authors investigate a SDMA grouping problem in MU MIMO in the context of 5G networks. Their approach consists in a partitioning process based on K-means to split MSs into spatially compatible clusters. After the clustering, is performed a scheduling based on the branch and bound algorithm to determine a sub-set o MSs from each cluster to compose a SDMA group.

Motivated by the above discussion, we investigate a SDMA grouping algorithm in a millimeter wave MU-MIMO scenario. The main contributions ot the work can be summarized as follows:

1) evaluation of a SDMA grouping algorithm;
2) evaluation of a hybrid precoding scheme and its impact on the total data rate.

The remainder of this work is organized as follows. We present in II the assumptions about our system model. III presents the adopted SDMA grouping algorithm, and in IV, we discuss the proposed hybrid precoding scheme. Performance results are discussed in V, and the main conclusions are drawn in Sections VI.

Francisco Hugo Costa Neto, e-mail: hugo@gtel.ufc.br; Tarcisio Ferreira Maciel, e-mail: maciel@gtel.ufc.br, Wireless Telecommunications Research Group, Department of Teleinformatics Engineering, Center of Technology, Federal University of Ceará. This work was supported by Ericsson Research, Sweden, and Ericsson Innovation Center, Brazil, under UFC.44 Technical Cooperation Contract Ericsson/UFC. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. Francisco Hugo Costa Neto was supported by CAPES under the grant 88882.183549/2018-01. T. F. Maciel would like to acknowledge CNPq for its financial support under the grants 426385/2016-0 and 308621/2018-2.

II. System Model

We consider the downlink of a MU-MIMO system based on OFDMA. The system is composed of one BS and a set $\mathcal{J}$ containing J MSs. The transmitter uses M antennas to send S_j data streams to N_j antennas at the jth receiver. Before transmission, for a given resource block (RB) and transmission time interval (TTI), the symbol vector $\mathbf{x}_j \in \mathbb{C}^{S_j \times 1}$ is filtered by the precoding matrix $\mathbf{F}_j \in \mathbb{C}^{M \times S_j}$. The filtered symbols are then transmitted through the channel associated with the RB and which response is represented by $\mathbf{H}_j \in \mathbb{C}^{N_j \times M}$. Thus, the prior-filtering receive vector $\mathbf{y}_j \in \mathbb{C}^{N_j \times 1}$ at the jth receiver is given by

$$\mathbf{y}_j = \mathbf{H}_j \mathbf{F}_j \sqrt{\mathbf{P}_j}\, \mathbf{x}_j + \sum_{i \neq j} \mathbf{H}_j \mathbf{F}_i \sqrt{\mathbf{P}_i}\, \mathbf{x}_i + \mathbf{z}_j, \tag{1}$$

where $\mathbf{P}_j \in \mathbb{R}^{S_j \times S_j}$ is the power matrix, given by $\alpha \mathbf{I}_{S_j}$, where α is the transmit power allocated to each stream associated to the jth MS and $\mathbf{I}_{S_j}$ is the $S_j \times S_j$ identity matrix; the second term on the right-hand side of (1) represents the MU interference, also known as intracell interference, caused by any MSs sharing the same RB; $\mathbf{z}_j \in \mathbb{C}^{N_j \times 1}$ is the additive Gaussian noise vector, whose elements are independent and identically distributed (IID) as $\mathcal{CN}(0, \sigma_{\mathbf{z}}^2)$.

The input symbol vector is normalized so that $\mathbb{E}\{\mathbf{x}_j \mathbf{x}_j^{\mathrm{H}}\} = \mathbf{I}_{S_j}$. The channel coefficient of a given RB corresponds to that associated with the middle subcarrier and the first transmitted orthogonal frequency division multiplexing (OFDM) symbol in a TTI or a subframe. Thus, we consider that the channel remains constant during resource allocation in a TTI and over an RB. Moreover, we assume that the required channel state information (CSI) is available at the transmitter and receivers.

At the receiver, the vector $\mathbf{y}_j$ is filtered by the decoding matrix $\mathbf{G}_j \in \mathbb{C}^{S_j \times N_j}$. Therefore, the post-filtering receive vector $\hat{\mathbf{y}}_j \in \mathbb{C}^{S_j \times 1}$ is given by

$$\hat{\mathbf{y}}_j = \mathbf{G}_j \mathbf{H}_j \mathbf{F}_j \sqrt{\mathbf{P}_j} \mathbf{x}_j + \mathbf{G}_j \sum_{i \neq j} \mathbf{H}_j \mathbf{F}_i \sqrt{\mathbf{P}_i} \mathbf{x}_i + \mathbf{G}_j \mathbf{z}_j. \tag{2}$$

We consider a multipath wireless channel model [9] to describe the response channel matrix $\mathbf{H}_j$. It can be expressed in terms of underlying physical paths as

$$\mathbf{H} = \sum_{p=1}^{N_p} \varphi_p \chi \mathbf{v}_r(\phi_{p,r}) \mathbf{v}_t^{\mathrm{H}}(\phi_{p,t}) e^{-j2\pi\tau_p f} e^{j2\pi\nu_p t}, \tag{3}$$

where, for each propagation path p, φ_p is the path gain; χ is the shadowing modeled lognormal random variable with standard deviation σ_{sh}; $\phi_{p,r}$ is the angle of arrival (AoA) at the receiver; $\phi_{p,t}$ is the angle of departure (AoD) at the transmitter; τ_p is the relative delay; f is the frequency of the central subcarrier of the RB; ν_p is the Doppler shift; $\mathbf{v}_r(\phi_{p,r}) \in \mathbb{C}^{N_r \times 1}$ is the response vector and $\mathbf{v}_t(\phi_{p,t}) \in \mathbb{C}^{N_t \times 1}$ is the steering vector. The multipath wireless channel model is represented in Fig. 1.

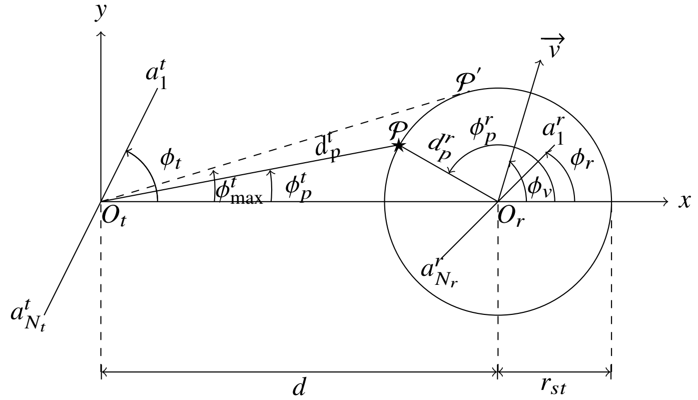

Fig. 1. Multipath wireless channel model for an $N_r \times N_t$ MIMO channel with local scatters around the MS.

We consider a general path loss model, whose definition in dB is given by

$$\psi_p = a \log_{10}(l_p) + b + c \log_{10}(f) \tag{4}$$

where l_p is the path length in meters; f is the frequency of the central subcarrier of the RB in GHz; parameters a, b and c are defined according to the propagation scenario in [10].

III. SDMA Grouping Problem

In our study, the SDMA grouping problem is divided into two parts. In the first part, the set $\mathcal{J}$ of all MSs of the system is divided into a set of clusters C, according to their channel characteristics. In the second part, we select one MS from each cluster C_i to form SDMA groups. The MSs are selected in order to reduce channel correlation, since we want to minimize the MU interference for those MSs in a same SDMA group.

The set of all possible clusters that can be built in a system with J MSs is defined as C_{max}. According to [11], the number of possible ways of partitioning J MSs into K clusters (non-empty and disjoint subsets) is given by Stirling numbers of the second kind as

$$|C_{max}| = \frac{1}{K!} \sum_{k=0}^{K} (-1)^k \binom{K}{k} (K-k)^J, \tag{5}$$

assuming that all MSs have $N_j = N$ antenas and considering that individual receive antennas can be selected for data reception.

The exhaustive search for suitable clusters consists in the evaluation of all possibilities of $C_{\max}$. In practice, this brute-force approach is an unfeasible task. In this study, we evaluate two different clustering strategies. On one hand, the random selection of MSs. On the other hand, we consider the partition MSs into sets of MSs with spatially correlated channels based on K-means.

The evaluated approach aims to cluster MSs into sets so that each MS belongs to the cluster with the nearest central characteristic, a subspace of the average channel covariance eigenspace. Given the channel matrix of MS j, $\mathbf{H}_j \in \mathbb{C}^{N_j \times M}$, the sample transmit covariance matrix $\tilde{\mathbf{H}}_j \in \mathbb{C}^{M \times M}$ is given by

$$\tilde{\mathbf{H}}_j = \frac{1}{K} \sum_{k=1}^{K} \mathbf{H}_{k,j}^{\mathrm{H}} \mathbf{H}_{k,j}, \tag{6}$$

where K, called TTI window size, indicates the number of channel matrix samples considered in the averaging process and $\mathbf{H}_{k,j}^{\mathrm{H}}$ is the conjugate transpose of the channel matrix $\mathbf{H}_{k,j}$.

The eigendecomposition of $\tilde{\mathbf{H}}_j$ can be written as

$$\tilde{\mathbf{H}}_j = \mathbf{D}_j \mathbf{\Lambda}_j \mathbf{D}_j^{-1}, \quad (7)$$

where $\mathbf{D}_j \in \mathbb{C}^{M\times M}$ defines the matrix composed of eigenvectors and $\mathbf{\Lambda}_j \in \mathbb{C}^{M\times M}$ is the diagonal matrix of eigenvalues.

The evaluated algorithm employs a greedy iterative approach that aims to find a partition that minimizes the distance between elements that belong to each cluster to the cluster average value. We define $\mathbf{d}_j \in \mathbb{C}^{M\times 1}$ as the vector of phases of the dominant eigenvector $\tilde{\mathbf{d}}_j$, i.e., the eigenvector associated to the highest eigenvalue of $\tilde{\mathbf{H}}_j$, i.e.,

$$\mathbf{d}_j = f_{\text{phase}}\left(\tilde{\mathbf{d}}_j\right), \quad (8)$$

where $f_{\text{phase}}(\cdot)$ returns a vector whose complex components have unitary absolute values, i.e., which captures only the phases of the vector passed as argument, and $\mathbf{v}_i \in \mathbb{C}^{M\times 1}$, called centroid, is a vector that describes the central characteristic of the i^{th} cluster C_i, which is given by

$$\mathbf{v}_i = f_{\text{phase}}\left(\frac{1}{|C_i|}\sum_{j\in C_i}\mathbf{d}_j\right), \quad (9)$$

where j indexes the MSs that currently belong to cluster C_i.

The first step of the algorithm is the initialization of centroids. In our study, we randomly select the dominant eigenvector of C out of the J MSs as initial cluster centroids. Each iteration of the algorithm consists in a clustering assignment followed by a centroid update. Given the group means $\mathbf{v}_i, i = 1,\ldots,C$, provided at iteration $t = 0$, in the group assignment step, each MS $j \in \mathcal{J}$ is assigned to the cluster $C_{i^\star}$ with closest mean as

$$C_{i^\star} = \arg\min_{i=1,\ldots,C} \|\mathbf{d}_j - \mathbf{v}_i\|_2^2. \quad (10)$$

In the centroid update step, new mean values $\mathbf{v}_i$ are computed for each cluster from the MSs in C_i using (9). The assignment and centroid update steps are carried out until convergence is reached. The output of the algorithm is a clustering of the MSs into disjoint clusters $C_i, i = 1,\ldots,C$, and a set of vectors $\{\mathbf{v}_1^{(t)}, \mathbf{v}_2^{(t)}, \ldots, \mathbf{v}_C^{(t)}\}$ obtained as the centroids of the clusters. Based on that, we determine the filters of transmission and reception, as described in Section IV.

In the following, given the partition of MSs, we select one MS $g_i = j^\star \in C_i$ from each cluster to create an SDMA group $\mathcal{G}$ containing C MSs (or streams). In our study, we consider two strategies to schedule the MSs. The first strategy randomly selects one MS from each cluster C_i to compose $\mathcal{G}$. The second strategy considers the spatial correlation between the MSs to create the SDMA group $\mathcal{G}$. In this case, in a first step, we select the MS with the highest gain to be the first element of $\mathcal{G}$. In the following, we compute the normalized scalar product between the dominant eigenvector of the first element of the SDMA group and that of the MSs from other clusters. Defining g_1 as the first element of $\mathcal{G}$ and the j^{th} MS from cluster C_i, the normalized scalar product is given by

$$\rho_{j,g_1} = \frac{|\tilde{\mathbf{d}}_j^H \tilde{\mathbf{d}}_{g_1}|}{\|\mathbf{d}_j\|_2 \|\mathbf{d}_{g_1}\|_2}. \quad (11)$$

The MS j, belonging to a cluster other than those of the MSs belonging to $\mathcal{G}$, with the lowest ρ is the selected to be included into the SDMA group $\mathcal{G}$. This same procedure is repeated with the all clusters until we achieve the group size C, i.e., until $|\mathcal{G}| = C$.

IV. Hybrid Beamforming Design

For each selected MS g in the SDMA group $\mathcal{G}$, we consider that a matched filter on the dominant receive eigenmode of the MS's channel will be employed, i.e., at the receiver side, $\mathbf{G}_g = \mathbf{u}_{1,g}^H \in \mathbb{C}^{1\times N_g}$, where

$$\mathbf{H}_g = \mathbf{U}_g \Sigma_g \mathbf{V}_g^H = \begin{bmatrix}\mathbf{u}_{1,g} & \ldots & \mathbf{u}_{N_g,g}\end{bmatrix} \Sigma_g \mathbf{V}_g^H \quad (12)$$

is the singular value decomposition (SVD) of the channel $\mathbf{H}_g \in \mathbb{C}^{N_g\times M}$ of the g^{th} MS in the SDMA group $\mathcal{G}$ and $\mathbf{u}_1$ is its dominant left-singular vector.

In our study, we adopt a system with a hybrid precoding scheme composed of an analog and a digital component. In the random clustering algorithm, the analog precoder is defined from the dominant eigenvectors of the covariance matrix. In the evaluated clustering algorithm, the analog precoder $\mathbf{F}_{\text{RF}} \in \mathbb{R}^{M\times C}$, is defined from the centroids of the clusters and can be written as

$$\mathbf{F}_{\text{RF}} = \begin{bmatrix}\mathbf{v}_1 & \mathbf{v}_2 & \ldots & \mathbf{v}_C\end{bmatrix}. \quad (13)$$

The analog precoder is assumed to have elements of equal magnitude, i.e., only phase shifting is performed in the analog domain. This justifies the procedure described in Section III, when we only considered the phases of the elements of the dominant eigenvector of the covariance matrix.

Given the total number $N_{\mathcal{G}} = \sum_{g\in\mathcal{G}} N_g$ of receive antennas in the SDMA group $\mathcal{G}$, we define the group channel matrix $\mathbf{H}_{\mathcal{G}} \in \mathbb{C}^{N_{\mathcal{G}}\times M}$ and the decoder matrix $\mathbf{G} \in \mathbb{C}^{C\times N_{\mathcal{G}}}$ based on the channel matrices of the selected MSs, so that can write

$$\mathbf{H}_{\mathcal{G}} = \begin{bmatrix}\mathbf{H}_1^{\mathrm{T}} & \mathbf{H}_2^{\mathrm{T}} & \ldots & \mathbf{H}_C^{\mathrm{T}}\end{bmatrix}^{\mathrm{T}}, \text{ and} \quad (14)$$

$$\mathbf{G} = \operatorname{diag}(\mathbf{u}_{1,1}^{\mathrm{H}}, \mathbf{u}_{1,2}^{\mathrm{H}}, \cdots, \mathbf{u}_{1,C}^{\mathrm{H}}). \quad (15)$$

Therefore, given the block diagonal decoder matrix $\mathbf{G}$, the group channel matrix $\mathbf{H}_{\mathcal{G}}$ and the analog precoder $\mathbf{F}_{\text{RF}}$, the equivalent channel matrix $\mathbf{H}_{\text{eq}} \in \mathbb{C}^{C\times C}$ is given by

$$\mathbf{H}_{\text{eq}} = \mathbf{G}\mathbf{H}_{\mathcal{G}}\mathbf{F}_{\text{RF}}. \quad (16)$$

There are different precoding techniques that either totally or partially suppress spatial interference or ignore it.

We evaluate two filters as digital precoders, namely MRT and ZF.

The MRT precoding is designed to maximize the transmitter signal to noise ratio (SNR). Based on that information, the precoding matrix $\mathbf{F}_{\text{BB}} \in \mathbb{C}^{C\times C}$ for the j^{th} MS is defined as

$$\mathbf{F}_{\text{BB}} = \frac{\mathbf{H}_{\text{eq}}^H}{\|\mathbf{H}_{\text{eq}}\|_F}. \quad (17)$$

The ZF precoding is conceived to decorrelate the transmit signals so that the signal at every receiver output is free of interference. The precoding matrix is defined as

$$\mathbf{F}_{\mathrm{BB}} = \frac{\mathbf{H}_{\mathrm{eq}}^{H}(\mathbf{H}_{\mathrm{eq}}\mathbf{H}_{\mathrm{eq}}^{H})^{-1}}{\|\mathbf{H}_{\mathrm{eq}}^{H}(\mathbf{H}_{\mathrm{eq}}\mathbf{H}_{\mathrm{eq}}^{H})^{-1}\|_F} \tag{18}$$

The total power constraint is enforced by normalizing the digital and analog filters, such that $\|\mathbf{F}_{\mathrm{RF}}\mathbf{F}_{\mathrm{BB}}\sqrt{\mathbf{P}_{\mathcal{G}}}\|_F^2 = p_{\mathrm{RB}}$, where $\mathbf{P}_{\mathcal{G}} \in \mathbb{R}^{C\times C}$ is the block diagonal power matrix resulting of the combination of the power matrices of each MS belonging to the SDMA group and p_{RB} is the power for a given RB. We consider that the number of clusters is equal to the number of radio frequency (RF) chains and streams, i.e., $S = C$. Therefore, the dimensions of $\mathbf{F}_{\mathrm{RF}}$ and $\mathbf{F}_{\mathrm{BB}}$ are compatible with the dimension of $\mathbf{F}$, so that $\mathbf{F} = \mathbf{F}_{\mathrm{RF}}\mathbf{F}_{\mathrm{BB}} \in \mathbb{C}^{M\times C}$.

The post-filtering receive vector of the group $\hat{\mathbf{y}}_{\mathcal{G}} \in \mathbb{C}^{C\times 1}$ is given by

$$\hat{\mathbf{y}}_{\mathcal{G}} = \mathbf{G}\mathbf{H}_{\mathcal{G}}\mathbf{F}_{\mathrm{RF}}\mathbf{F}_{\mathrm{BB}}\sqrt{\mathbf{P}_{\mathcal{G}}}\,\mathbf{x}_{\mathcal{G}} + \mathbf{G}\mathbf{z}_{\mathcal{G}}, \tag{19}$$

where $\mathbf{x}_{\mathcal{G}} \in \mathbb{C}^{C\times 1}$ is the group symbol vector and the $\mathbf{z}_{\mathcal{G}} \in \mathbb{C}^{N_{\mathcal{G}}\times 1}$ is the group noise vector.

Defining $\mathbf{Q} = \mathbf{G}\mathbf{H}_{\mathcal{G}}\mathbf{F}\sqrt{\mathbf{P}_{\mathcal{G}}} \in \mathbb{C}^{C\times C}$, the average signal to interference-plus-noise ratio (SINR) perceived by the stream i can be calculated as

$$\Gamma_i = \frac{|\mathbf{Q}_{ii}|^2}{\sum\limits_{j\neq i}^{S} |\mathbf{Q}_{ij}|^2 + \sigma_z^2}, \tag{20}$$

where σ_z^2 is the average noise power. The data rate of stream i is calculated according to Shannon capacity formula [12] and is given by

$$C_i = B\,\log_2(1+\Gamma_i), \tag{21}$$

where B is the bandwidth of the RB.

V. Results

We consider a single cell system with a carrier frequency of 28 GHz and a bandwidth of 100 MHz. According to [13, Table 2], these parameters imply in a set of 125 RBs, each one composed of 12 subcarriers equally spaced of 60 kHz. Furthermore, the number of subframes per frame is 10, each subframe has 14 symbols and the TTI duration is 0.25 ms. We assume the one ring scattering channel [14], with the propagation effects modeled according to the urban micro (UMi) street canyon deployment proposed in [10]. Therefore, the path loss parameters are $a = 19.8$, $b = 32.4$ and $c = 20.0$. The AoDs are uniformly distributed in the range $[5°, 15°]$. The total power is fixed for all precoders with equal power allocation (EPA) among RBs. Other relevant simulation parameters are listed in Table I.

TABLE I

Simulation Parameters

Parameter	Symbol	Value	Unit
Simulation time	T	25	ms
Number of simulation rounds	–	100	–
Cell radius	R_c	100	m
Total transmit power	P_t	35	dBm
Noise figure	ζ	9	dB
Noise spectral density	ξ	-174	dBm/Hz
Number of paths	N_p	7	–
Shadowing standard deviation	σ_{sh}	3.1	dB

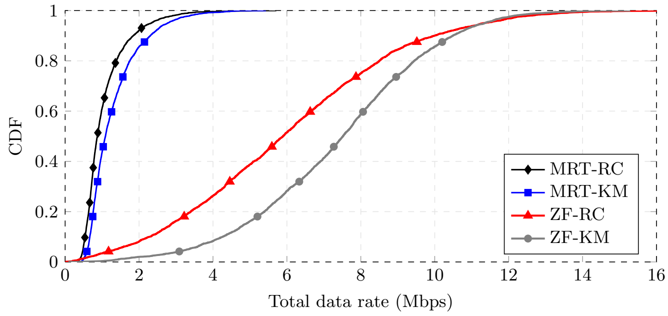

Fig. 2. Evaluation of MU-MISO scenario considering different clustering algorithms and decoders.

We assume a set $\mathcal{J}$ of 40 MSs uniformly distributed inside 4 circular regions, which have the same number of MSs and are characterized by its radius, distance and angle from its center to the BS. These parameters are randomly generated so that superposition of regions is allowed, but the MSs must lie inside a sector of 120° of the cell.

Initially, we consider a multi-user multiple input single output (MU-MISO) scenario, where the BS is equipped with a uniform linear array (ULA) with $M = 64$ antennas separated of half-wavelength. In Fig. 2, we show the cumulative distribution function (CDF) of the total data rate for our system considering the effect of the proposed SDMA grouping solution. First, we partition the MSs into $C = 4$ clusters using random scheduling (RS) or K-means (KM) clustering. Then, we randomly select one MS from each cluster to compose the SDMA group. Given the SDMA group, we determine the analog and digital precoders. We evaluate two digital precoders, namely ZF and MRT. Initially, when we consider ZF the effect of MSs clustering is clearly observed. Since this precoder aims to cancel interference, when we use KM the selected MSs' channels are likely spatially uncorrelated. Therefore, the signals sent to these MSs can be separated in space more efficiently. However, when we consider MRT as digital precoder this gain is not achieved, since it only considers the channel of each MS separately independently of the MU interference.

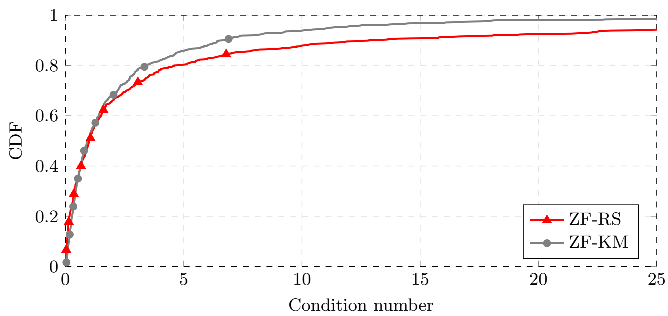

Fig. 3. CDF of the condition number of the equivalent channel matrix, $\mathbf{H}_{\mathrm{eq}}$.

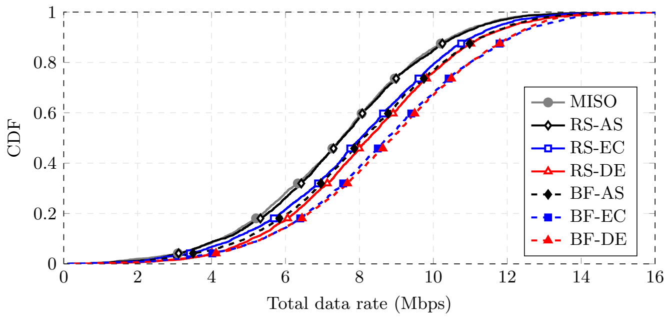

Fig. 4. Evaluation of MU-MIMO scenario considering different clustering algorithms and decoders.

The clustering of MS determines the characteristics of the analog precoder $\mathbf{F}_{\text{RF}}$. According to (16), it also impacts the equivalent channel matrix $\mathbf{H}_{\text{eq}}$. KM aims to partition MSs into clusters that are spatially compatible. As a consequence, we observe an enhancement of 25% of the total data rate when we compare the KM and RC algorithms. Thus, the equivalent channel matrix is better conditioned in comparison with RS. As it can be seen in Fig. 3, the CDF of the condition number of the equivalent channel matrix considering RS is higher than when KM is considered. Therefore, KM combined with ZF exploits the spatial compatibility better, mitigating more efficiently the MU interference and, consequently, enhancing the total data rate.

In the following, we consider a MU-MIMO scenario, where the BS is equipped with a ULA with 64 antennas and each MS has a ULA with 2 antennas. In Fig. 4, we compare the CDF of the total data rate of MU-MISO to the MU-MIMO considering KM and ZF as digital precoder. For the MU-MIMO scenario we consider different decoder designs, namely antenna selection (AS), equal combining (EC) of the signal between receive antennas, and the dominant eigenmode (DE) of the receive covariance matrix.

The DE design obtains the weights that maximize the output SINR. EC, despite of being simpler, results in an improvement of data rate that is comparable to that achieved by DE. We can observe that the MIMO with selection of one antenna does not lead to gains of the total data rate in comparison with MU-MISO, since it does not explore receive diversity. Therefore, the best fit (BF)-DE configuration provides a total date rate 30% higher than MU-MISO. The scheduling of MSs considering spatial correlation BF enhances 12.5% of the total data rate in comparison with RS, since MU interference is mitigated more effectively in comparison with the random selection.

VI. Conclusions

In this study, we evaluated a solution to the SDMA grouping problem that is composed of two parts. Firstly, we partition MSs into clusters containing spatially correlated MSs while at the same time MSs from different clusters are likely spatially compatible. Therefore, secondly we select MSs from different clusters to build an SDMA group so that the MU interference is minimized. Moreover, we employ a hybrid beamforming scheme. The analog precoder is based on the channel information obtained from clustering while different precoders and decoders are evaluated. The simulation results indicate that the evaluated clustering algorithm partitions MSs appropriately and the BF schedules MSs to exploit spatial compatibility more effectively. When the ZF is considered as digital precoding scheme and DE as decoder, an increase of the total data rate is obtained compared to the cases employing MRT precoding.

References

[1] M. Agiwal, A. Roy, and N. Saxena, “Next Generation 5G Wireless Networks: A Comprehensive Survey,” *IEEE Communications Surveys and Tutorials*, vol. 18, no. 3, pp. 1617–1655, 2016.

[2] E. Castaneda, A. Silva, A. Gameiro, and M. Kountouris, “An Overview on Resource Allocation Techniques for Multi-User MIMO Systems,” *IEEE Communications Surveys and Tutorials*, vol. 19, no. 1, pp. 239–284, 2017.

[3] T. F. Maciel and A. Klein, “On the Performance, Complexity, and Fairness of Suboptimal Resource Allocation for Multiuser MIMO OFDMA Systems,” *IEEE Transactions on Vehicular Technology*, vol. 59, no. 1, pp. 406–419, Jan. 2010.

[4] A. Zubow, J. Marotzke, D. Camps-Mur, and X. Perez-Costa, “sGGSA: An SDMA-OFDMA Scheduling Solution,” in *European Wireless Conference*, Apr. 2012. [Online]. Available: http://ieeexplore.ieee.org/document/6216823/

[5] Y. J. Zhang and K. B. Letaief, “An Efficient Resource-Allocation Scheme for Spatial Multiuser Access in MIMO/OFDM Systems ,” *IEEE Transactions on Communications*, vol. 53, no. 1, pp. 107–116, Jan. 2005.

[6] J. Nam, A. Adhikary, J.-Y. Ahn, and G. Caire, “Joint Spatial Division and Multiplexing: Opportunistic Beamforming, User Grouping and Simplified Downlink Scheduling,” *IEEE Journal of Selected Topics in Signal Processing*, vol. 8, no. 5, pp. 876–890, Oct. 2014.

[7] M. Moretti, L. Sanguinetti, and X. Wang, “Resource Allocation for Power Minimization in the Downlink of THP-Based Spatial Multiplexing MIMO-OFDMA Systems ,” *IEEE Transactions on Vehicular Technology*, vol. 64, no. 1, pp. 405–411, Jan. 2015.

[8] W. V. F. Mauricio, D. C. Araujo, F. H. C. Neto, F. R. M. Lima, and T. F. Maciel, “A Low Complexity Solution for Resource Allocation and SDMA Grouping in Massive MIMO Systems,” 2018, pp. 1–6.

[9] W. U. Bajwa, J. Haupt, A. M. Sayeed, and R. Nowak, “Compressed Channel Sensing: A New Approach to Estimating Sparse Multipath Channels,” *Proceedings of the IEEE*, vol. 98, no. 6, pp. 1058–1076, Jun. 2010.

[10] M. Peter and K. Sakaguchi, “Measurement Campaigns and Initial Channel Models for Preferred Suitable Frequency Ranges,” Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications (mmMAGIC), Deliverable 2.1, Mar. 2016. [Online]. Available: https://bscw.5g-mmmagic.eu/pub/bscw.cgi/d94832/mmMAGIC_D2-1.pdf

[11] M. J. Zaki and W. M. Jr, *Data Mining and Analysis: Fundamental Concepts and Algorithms*. Cambridge University Press, 2014.

[12] T. M. Cover and J. A. Thomas, *Elements of Information Theory*, 2nd ed., J. W. . Sons, Ed. John Wiley & Sons, 2006.

[13] A. A. Zaidi, R. Baldemair, H. Tullberg, H. Bjorkegren, L. Sundstrom, J. Medbo, C. Kilinc, and I. D. Silva, “Waveform and Numerology to Support 5G Services and Requirements,” *IEEE Communications Magazine*, vol. 54, no. 11, pp. 90–98, Nov. 2016.

[14] M. Patzold, *Mobile Radio Channels*, 2nd ed. John Wiley & Sons, 2012.