マルチユーザMIMO分散アンテナシステムにおける ダイナミッククラスタリング手法

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あらまし　分散アンテナシステム（DAS: distributed antenna system）の面的展開を考えた時，広大なエリアにおいて全送信アンテナを連携させてプリコーディングを行うと，その係数を求める際の行列サイズが大きくなるため演算量が膨大となってしまう．このため，行列を分割して演算量を低減するためにも送信アンテナとユーザを組に分けるクラスタリングを行う必要が生じる．本稿では，直交波周波数分割多重（OFDM: orthogonal frequency division multiplexing）に基づいたマルチユーザMIMO DASにおいて新しいダイナミッククラスタリング手法を提案し，総和レートの改善について検討を行う．また，提案手法が一般的な伝搬環境にも適用できることを検討するために，空間相関性を有するシャドウイング減衰をも考慮に入れる．計算機シミュレーション結果から，従来のクラスタリング手法と比べて提案手法が高い総和レートを実現することを明らかにする．
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An Efficient Scheme for Dynamic Clustering in OFDM-Based Multiuser MIMO Distributed Antenna Systems

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Abstract　To establish a wide service area of multiuser (MU) MIMO distributed antenna system (DAS), the use of dynamic clustering scheme (CS) is necessary to reduce a huge amount of computation in precoding which is widely applied in MU-MIMO communication systems. In this study, we propose a novel and efficient algorithm for dynamic clustering by employing a orthogonal frequency division multiplexing based MU-MIMO DAS and investigate its performance by observing the cumulative distribution function and expectation of the system sum rate. We also compare the characteristics of our proposed CS and other classical dynamic CSs, for instance, exhaustive search, norm-based and location-based adaptive algorithm, in terms of sum rate improvement. Moreover, in order to make our results more universality, we further introduce the spatial correlation in the considered system, in particular, the spatial correlation in shadowing that exists widely in DASs. Computer simulation results indicate that our proposed CS provides better performance than the existing schemes in the literature and can achieve similar sum rate as the exhaustive search.
Key words　Dynamic clustering scheme, Multiuser MIMO, Distributed antenna systems, Spatial correlation, Sum rate, Zero-forcing precoding

1. Introduction

With the constantly growing demand for higher data rates in wireless communication services, it is necessary to enhance the communication speed and channel capacity. Recently, various techniques have been proposed to increase the system capacity. Among these techniques, multiple-input multiple-output (MIMO) transmission has attracted considerable attention because it can provides high data rates and link reliability without additional bandwidth or power [1]. However, in practice the number of antennas at user cannot be made arbitrarily large due to physical constrains. Another well-known technique is the distributed antenna system (DAS), as it decreases access distance and spatial correlation by geographically distributing the antennas, thereby can provide macro-diversity and enhances the capacity [2].

By combining multiuser (MU) MIMO techniques and DAS with linear precoding which is processed in transmit side [3], the required computational complexity and the number of antennas at users can be reduced because users can demodulate the signals without any MIMO detection schemes while keeping the advantages of DAS and MIMO. However, to establish a wide service area of MU-MIMO DAS, a large amount of channel state information (CSI) at transmit side that can significantly improve the system performance must be required; more important is, the complexity of obtaining precoding weight matrices, for instance, running the pseudo-inverse transpose of channel attenuation matrix under zero-forcing (ZF) precoding scheme, constantly increases with the increasing of the number of users and base stations (BSs). Therefore, creating a large-scale MU-MIMO DAS in realistic environment is still a challenge problem.

Fortunately, an orthogonal frequency division multiplexing (OFDM) based clustering scheme (CS) is considered as an effective approach to solve the existing problems mainly because as OFDM can split a wideband channel into many narrowband channels, the precoding techniques can be performed independently for each subcarrier, so that, in each subcarrier, the precoding weight matrices can be obtained with low complexity. Specifically, in [4], a static CS which depends on the locations of users and BSs with linear precoding have been proven to significantly improve the spectral efficiency of cellular systems. The limitations in this CS, however, is a lack of diversity with respect to changing channel conditions since clusters are static. On the other hand, exhaustively searching over all possible user-BS combinations for each channel realization and selecting the one that yields maximum capacity or other performance measures is a optimum algorithm for dynamic clustering, however, it is not practically feasible because the computational complexity exponentially increases as the number of users and BSs increases. To solve this problem, for instance, in [5], a norm-based algorithm which selects the antennas corresponding to the rows and/or columns of channel gain matrix with the largest Euclidean norm have been proposed. Although simple and computationally efficient, this algorithm incurs capacity loss as it is suboptimal.

Motivated by the previous discussion, to dynamically format clusters with low complexity and satisfactory performance on sum rate, in this study, we propose a novel and efficient algorithm for dynamic clustering by employing a OFDM-based MU-MIMO DAS and investigate its performances by observing the cumulative distribution function (CDF) and expectation of the system sum rate. We also compare the characteristics of our proposed CS and other classical dynamic CS, for instance, exhaustive search, norm-based and location-based adaptive (LOCA) algorithm, in terms of sum rate improvement. Moreover, we further introduce the spatial correlation in considered system, in particular, the spatial correlation in shadowing that exists widely in DASs, to make our results more universality.

The remainder of this paper is organized as follows. In Sect. 2., we define the system model and describe the mathematical background for the channel attenuation model in which the spatial correlation is considered. In the same section, we also derive some expressions that can calculate the system sum rate and formulate the problems that we must solved. In Sect. 3., a novel and efficient dynamic CS targeting to maximize the system sum rate is presented. In Sect. 4., we compare the characteristics of our proposed CS and other classical dynamic CS using simulation method. Concluding remarks can be found in Sect. 5..

Notations: We use upper- and lower-case boldface to denote matrices and vectors, respectively. The $n \times n$ identity matrix is denoted by $\mathbf{I}_n$, and the (i, j)th element of a matrix is denoted by $[\boldsymbol{A}]_{ij}$. The expectation is given by $\mathcal{E}\{\cdot\}$, and we use calligraphic font $\mathcal{A}$ to denote a integer collection and use $|\mathcal{A}|$ to present the size of this collection. The symbols $(\cdot)^\dagger$ and $(\cdot)^{\mathrm{H}}$ represent the pseudo-inverse and Hermitian transpose of a matrix, respectively, and "$\circ$" denotes the Hadamard product, i.e., $[\boldsymbol{A} \circ \boldsymbol{B}]_{ij} = [\boldsymbol{A}]_{ij}[\boldsymbol{B}]_{ij}$. To distinguish the square root of a matrix $\boldsymbol{A}^{\frac{1}{2}}$, we use $\boldsymbol{A}^{\frac{1}{2}\circ}$ to denote the positive square root of $\boldsymbol{A}$ with respect to the Hadamard product such that $\boldsymbol{A}^{\frac{1}{2}\circ} \circ \boldsymbol{A}^{\frac{1}{2}\circ} = \boldsymbol{A}$. The symbol $\sim \mathcal{CN}(M, \Sigma)$ denotes a complex Gaussian random variable (RV) with a mean M and covariance Σ, and $\mathrm{diag}\{\cdot\}$ and $\mathrm{vec}\{\cdot\}$ represent a diagonal matrix and a column vector consisting of their inside elements, respectively.

2. System model

We consider a OFDM-based MU-MIMO DAS. The system consists of $|\mathcal{B}|$ ($\mathcal{B} := \{1, \cdots, B\}$ indexed with b) distributed BSs each equipped with single antenna connected to a central processor (CP) and $|\mathcal{U}|$ ($\mathcal{U} := \{1, \cdots, U\}$ indexed with u) active users are uniformly distributed. We define the generalized DAS as the one in which all of BSs are symmetrically distributed in a rectangular coverage area, and the distance between two adjacent BS typically be set as tens of hundreds

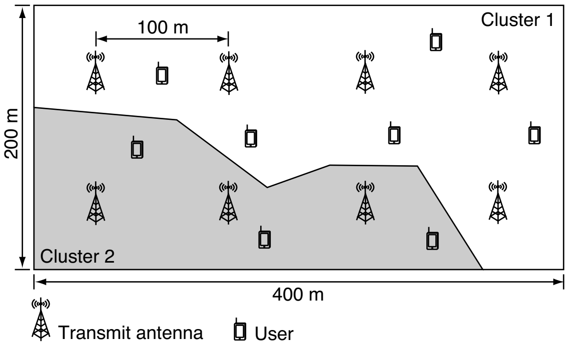

Fig. 1 Illustration of a OFDM-based MU-MIMO DAS in which $B = 8$ cooperation BSs simultaneously serve $U = 8$ users using $J = 2$ clusters that are represented by the shaded and blank areas.

of meters [6]. Optical fibers are employed to transfer information and signaling between the BSs and the CP, and all signals are jointly processed in this CP. A downlink scenario is considered where $|\mathcal{J}|$ ($\mathcal{J} := \{1, \cdots, J\}$ indexed with j) OFDM subcarrier can be allocated to J clusters. In cluster j, $|\mathcal{B}_j| \leqslant B$ BSs cooperate under a linear precoding framework, and simultaneously communicate with $|\mathcal{U}_j| \leqslant U$ users using subcarrier j. Moreover, to simplify our system model and achieve a total number of spatial degrees of freedom (DOF) of $|\mathcal{B}_j|$ in cluster j using a low complexity MIMO linear precoding scheme, such as ZF precoding, we assume that each user is equipped with one antenna and let $|\mathcal{U}_j| = |\mathcal{B}_j| \forall j$ [7]. Note that, in this study, to further reduce the complexity of system, we allow more than one user or BS to share a subcarrier, however, each user or BS only uses one subcarrier at most, i.e., it follows that for each subcarrier j, if $b \in \mathcal{B}_j$ and $u \in \mathcal{U}_j$, $b \notin \mathcal{B}_{j'}$ and $u \notin \mathcal{U}_{j'}$ for all $j \neq j'$. A illustration of the system under consideration is depicted in Fig. 1.

2.1 Channel model

In this study, composite fading channels (i.e., with both Rayleigh fading and shadowing) are considered. The channel matrix from B BSs to U users in jth subcarrier can be expressed as

$$\boldsymbol{H}(\mathcal{U}, \mathcal{B}, j) = \boldsymbol{D}^{\frac{1}{2}\circ}(\mathcal{U}, \mathcal{B}, j) \circ \boldsymbol{S}_{\mathrm{cor}}^{\frac{1}{2}\circ}(\mathcal{U}, \mathcal{B}, j) \circ \boldsymbol{R}_{\mathrm{cor}}(\mathcal{U}, \mathcal{B}, j), \quad (1)$$

where the entries of the matrix $\boldsymbol{D}(\mathcal{U}, \mathcal{B}, j) \in \mathbb{R}^{U \times B}$ represent the path loss. Thus, $\boldsymbol{D}(\mathcal{U}, \mathcal{B}, j) = (\boldsymbol{d}_1, \cdots, \boldsymbol{d}_B)$ for all j, where the vector $\boldsymbol{d}_b \in \mathbb{R}^{U \times 1}$ has U elements, and the uth element can be expressed as $[\boldsymbol{d}_b]_u = d_{ub}^{-\zeta}$, where d_{ub} denotes the distance between the uth user and the bth BS, and ζ is the path loss exponent.

The entries of the matrix $\boldsymbol{S}_{\mathrm{cor}}(\mathcal{U}, \mathcal{B}, j) \in \mathbb{R}^{U \times B}$ represent the spatially correlated shadowing; thus, $\boldsymbol{S}_{\mathrm{cor}}(\mathcal{U}, \mathcal{B}, j) = (\boldsymbol{s}_{1j}, \cdots, \boldsymbol{s}_{Bj})$ with the spatial autocorrelation matrix $\boldsymbol{\Theta}_{\mathrm{S,r}} \in \mathbb{R}^{U \times U}$ among every row, where the vector $\boldsymbol{s}_{bj} \in \mathbb{R}^{U \times 1}$ has U elements, and the uth element can be expressed as $[\boldsymbol{s}_{bj}]_u = 10^{0.1 s_{ubj}}$, where $s_{ubj} \in \mathcal{N}(\mu_{ubj}, \sigma_{ubj}^2)$ is a Gaussian RV. From the previous experiments reported in [8], it was found that the shadowing autocorrelation (SAC), i.e., the correlation between the RVs s_{ubj} and $s_{u'bj}$, can be modeled via an exponential decay function; therefore, the (u, u')th element of matrix $\boldsymbol{\Theta}_{\mathrm{S,r}}$ can be obtained from

$$[\boldsymbol{\Theta}_{\mathrm{S,r}}]_{uu'} = \exp\left(-\frac{L_{uu'}}{d_{\mathrm{cor,r}}} \ln 2\right), \quad (2)$$

where $L_{uu'}$ denotes distance between the uth user and the u'th user, and $d_{\mathrm{cor,r}}$ is the shadowing correlation distance on the user's side.

The spatial correlation between the RVs s_{ubj} and $s_{ub'j}$ can be modeled using a suitable shadowing cross-correlation (SCC) model, which should incorporate two key variables, i.e., the angle-of-arrival (AOA) difference that represents the angle between the two paths from different BSs to the user and the relativity of the two path lengths [9]. The verified SCC model in [9] is taken into account in this study. The SCC coefficient for two BSs with distances d_{ub} and $d_{ub'}$ ($d_{ub} < d_{ub'}$) from the user u and the AOA difference of $\theta_{ubb'}$ in this model can be expressed as

$$\epsilon_{ubb'} = \begin{cases} \sqrt{\frac{d_{ub}}{d_{ub'}}} & 0 \leqslant \theta_{ubb'} < \theta_{\mathrm{cor,t}} \\ \left(\frac{\theta_{\mathrm{cor,t}}}{\theta_{ubb'}}\right)^{\kappa} \sqrt{\frac{d_{ub}}{d_{ub'}}} & \theta_{\mathrm{cor,t}} \leqslant \theta_{ubb'} \leqslant \pi, \end{cases} \quad (3)$$

where κ is referred to as a parameter determined in practice by the size and height of the terrain and the height of the BS [9]. $\theta_{\mathrm{cor,t}}$ corresponds to the threshold angle depending upon the shadowing correlation distance $d_{\mathrm{cor,t}}$ on the transmit side and can be defined as

$$\theta_{\mathrm{cor,t}} = 2 \tan^{-1}\left(\frac{d_{\mathrm{cor,t}}}{2 d_{ub}}\right). \quad (4)$$

On the basis of these descriptions of the SAC and SCC, the matrix $\boldsymbol{S}_{\mathrm{cor}}(\mathcal{U}, \mathcal{B}, j)$ can be obtained from

$$\boldsymbol{S}_{\mathrm{cor}}(\mathcal{U}, \mathcal{B}, j) = \boldsymbol{\Theta}_{\mathrm{S,r}}^{\frac{1}{2}} \cdot \mathrm{diag}\{\boldsymbol{s}_{\mathrm{i.i.d.},uj}\}_{u=1}^{U} \cdot \mathrm{vec}\left\{\boldsymbol{\Theta}_{\mathrm{S,t},u}^{\frac{1}{2}}\right\}_{u=1}^{U}, \quad (5)$$

where $\boldsymbol{s}_{\mathrm{i.i.d.},uj} \in \mathbb{R}^{1 \times B} \forall u, j$ has B mutually independent lognormal RVs whose logarithm follow the normal distribution with mean μ_{ubj} and variance σ_{ubj}^2. Moreover, the vectors $\boldsymbol{s}_{\mathrm{i.i.d.},uj} \forall u$ are also mutually independent. The matrix $\boldsymbol{\Theta}_{\mathrm{S,t},u} \in \mathbb{R}^{B \times B}$ represents a SCC matrix for user u. The (b, b')th element of $\boldsymbol{\Theta}_{\mathrm{S,t},u}$ is the SCC coefficient between the bth and b'th BS that can be calculated by (3).

The entries of the matrix $\boldsymbol{R}_{\mathrm{cor}}(\mathcal{U}, \mathcal{B}, j) \in \mathbb{C}^{U \times B}$ represent the spatially correlated Rayleigh fading that can be obtained from the following expression:

$$\boldsymbol{R}_{\rm cor}(\mathcal{U},\mathcal{B},j)=\boldsymbol{\Theta}_{\rm R,r}^{\frac{1}{2}}\cdot\boldsymbol{R}_{\rm i.i.d.}(\mathcal{U},\mathcal{B},j)\cdot\boldsymbol{\Theta}_{\rm R,t}^{\frac{1}{2}},\tag{6}$$

where the entries of $\boldsymbol{R}_{\rm i.i.d.}(\mathcal{U},\mathcal{B},j)\in\mathbb{C}^{U\times B}\,\forall j$ are modeled as i.i.d. $\mathcal{CN}(0,1)$ RVs. $\boldsymbol{\Theta}_{\rm R,r}$ and $\boldsymbol{\Theta}_{\rm R,t}$ are Rayleigh fading correlation matrices on the user and transmit sides. From previous studies, the fading spatial correlation can be modeled via exponential correlation with

$$[\boldsymbol{\Theta}_{\rm R,r}]_{uu'}=\beta_{\rm r}^{|u-u'|}\tag{7}$$

and

$$[\boldsymbol{\Theta}_{\rm R,t}]_{bb'}=\beta_{\rm t}^{|b-b'|},\tag{8}$$

where $\beta_{\rm r},\beta_{\rm t}\in[0,1)$ [3].

It must be noted that, the authors in [10] investigated the correlations of the shadowing and fading between the different frequency bands in urban environments by some experimental measurements. The results show that there is a high correlation for the shadowing coefficients between all frequency bands; inversely, the correlation of the fading between different frequency bands is very small. On the basis of this facts and to reasonably simplify the channel model, in this study, we assume that, the shadowing attenuations between different frequencies, i.e., the matrices $\mathrm{diag}\{\boldsymbol{s}_{{\rm i.i.d.},uj}\}_{u=1}^{U}\,\forall j$, are completely correlated; in this other hand, the fading attenuations between different frequencies, i.e., the matrices $\boldsymbol{R}_{\rm i.i.d.}(\mathcal{U},\mathcal{B},j)\,\forall j$, are mutually independent.

2.2 Sum rate and problem formulation

Through these composite fading channels, the received signal in cluster j is expressed as

$$\boldsymbol{y}_j=\boldsymbol{H}\left(\mathcal{U}_j,\mathcal{B}_j,j\right)\boldsymbol{W}_j\boldsymbol{P}_j\boldsymbol{x}_j+\boldsymbol{n},\tag{9}$$

where $\boldsymbol{y}_j\in\mathbb{C}^{|\mathcal{U}_j|\times 1}$ is the received signal vector, and $\boldsymbol{x}_j\in\mathbb{C}^{|\mathcal{U}_j|\times 1}$ is the vector of the transmitted symbols that are drawn from a zero-mean Gaussian codebook with a unit average power, i.e., the entries of $\boldsymbol{x}_j$ are modeled as $\mathcal{CN}(0,1)$ RVs. The block length of the codebook is sufficiently long so that it encounters all possible channel realizations for ergodicity. The complex noise term $\boldsymbol{n}\in\mathbb{C}^{|\mathcal{U}_j|\times 1}$ is zero mean with $\mathcal{E}\{\boldsymbol{n}\boldsymbol{n}^{\rm T}\}=N_0\mathbf{I}_{|\mathcal{U}_j|}$, where N_0 is the noise power. $\boldsymbol{W}_j=\{\boldsymbol{w}_{1j},\cdots,\boldsymbol{w}_{|\mathcal{U}_j|j}\}$ is the precoding weight matrix with element $\boldsymbol{w}_{uj}\in\mathbb{C}^{|\mathcal{B}_j|\times 1}$, and the matrix $\boldsymbol{P}_j=\mathrm{diag}\{p_{uj}\}_{u=1}^{|\mathcal{U}_j|}\in\mathbb{R}^{|\mathcal{U}_j|\times|\mathcal{U}_j|}$ is the transmit power scaling factor matrix.

We hereafter focus on the sum rate in cluster j with ZF precoding. We assume that subcarrier $j\in\mathcal{J}$ has a bandwidth that is much smaller than the coherence bandwidth of the channel, and the instantaneous CSI on all the subcarriers of all the user-BS pairs are known to the CP. Hereafter, for the case under consideration, the ZF precoding weight matrix is expressed as $\boldsymbol{W}_j=\boldsymbol{H}\left(\mathcal{U}_j,\mathcal{B}_j,j\right)^{\dagger}$ [3]. Therefore, we can formulate the problem mathematically as

$$\arg\max_{\mathcal{U}_j,\mathcal{B}_j}C=\sum_{j=1}^{J}\sum_{u=1}^{|\mathcal{U}_j|}\log_2\left(1+\frac{p_{uj}}{N_0}\right),\tag{10}$$

and the maximization is subjected to the constraint

$$P_{\rm t}=\sum_{j=1}^{J}\sum_{u=1}^{|\mathcal{U}_j|}p_{uj}\left|\boldsymbol{w}_{uj}\right|^2,\tag{11}$$

where $P_{\rm t}$ is total transmit power.

It is worth mentioning that, once temporary sets $\mathcal{U}_j$ and $\mathcal{B}_j$ are found, the optimization problem (10) with power constraint (11) can be solved using the well-known waterfilling method; then according to this optimal solution about p_{uj}, we can decide whether to update the sets $\mathcal{U}_j$ and $\mathcal{B}_j$ to find the best assignment. However, more time should be used for the simulation owing to the complexity of calculating the Lagrange multipliers in this method. On the basis of this fact, consider that our major work is to verify the effectiveness of the proposed dynamic CS and control the simulation time to an acceptable level, we assume that the total transmit power $P_{\rm t}$ is uniformly allocated among all of active subcarriers, and the allocated power in each active subcarrier is further uniformly distributed to the users. Thereafter, we can simply optimization problem (10) to (12) [3]. Note that, in some time, not all subcarriers are used owing to bad channel conditions, thereby the parameter $\hat{J}$ in (12) be defined as the number of active subcarriers. Moreover, the sum rate corresponding to unused subcarriers in simplified optimization problem (12) be set as zero for its feasibility.

3. Dynamic clustering schemes

In this section, there is a description of the proposed dynamic CS that aim to maximize the sum rate. The problem of sum rate maximization can be expressed mathematically as (12), where the probability distribution of sum rate C is obtained over all channel realizations. Our target is investigating the performance of proposed scheme by observing the CDF and expectation of the sum rate in considered system.

The optimum algorithm to format all of clusters is firstly deciding all possible size of each cluster for each channel realization with constrain $\sum_{j=1}^{J}|\mathcal{U}_j|=U$; secondly, corresponding to one possibility, exhaustive searching over all possible user and BS combinations to obtain a cluster formation; finally, selecting the one that yields maximum sum rate from all of possible cluster formations. This algorithm is not practically feasible due to the computational complexity.

In this study, the following algorithm is proposed for dynamic clustering with solving the problem we mentioned,

1) **Step 1:**

  a) Set $\mathcal{U}_j=\varnothing$, $\mathcal{B}_j=\varnothing$, for all subcarrier j.

$$\arg\max_{\mathcal{U}_j,\mathcal{B}_j} C = \sum_{j=1}^{J}\sum_{u=1}^{|\mathcal{U}_j|}\log_2\left(1+\frac{P_{\mathrm{t}}}{\hat{J}|\mathcal{U}_j|N_0}\left[\left(\boldsymbol{H}\left(\mathcal{U}_j,\mathcal{B}_j,j\right)\boldsymbol{H}\left(\mathcal{U}_j,\mathcal{B}_j,j\right)^{\mathrm{H}}\right)^{-1}\right]_{uu}^{-1}\right) \tag{12}$$

2) **Step 2:**
   a) Find one user-BS pair with subcarrier j from sets $\mathcal{U}$, $\mathcal{B}$ and $\mathcal{J}$ that maximize the sum rate with the selected users and BSs which have been assigned in $\mathcal{U}_j$ and $\mathcal{B}_j$. The sum rate is calculated using (12).

3) **Step 3:**
   a) Add this user and BS to sets $\mathcal{U}_j$ and $\mathcal{B}_j$ corresponding to subcarrier j, respectively.
   b) Remove this user and BS from sets $\mathcal{U}$ and $\mathcal{B}$.

4) **Step 4:**
   a) Go to **step 2**, continue in the same fashion until all the users and BSs are selected and clusters are formatted.

4. Simulation parameters and results

4.1 Simulation parameters

In this simulation, a homogeneous area consists of a rectangular cell with length 400 m and width 200 m. As shown in Fig. 1, $B = 8$ transmit antennas are distributed with 100 m interantenna distance, and $U = 8$ users are assumed to be uniformly distributed in this area. The parameter κ in the SCC model (3) is set to 0.3, and the transmit antenna height is set to 15 m [9]. We consider a simplified OFDM system with two subcarriers, one is 2.000×10^9Hz and the other one is 2.001×10^9Hz. According to experimental results from [11] and noting that we assumed a homogeneous area, the shadowing parameters μ_{ubj} and σ_{ubj} at 2.000×10^9Hz frequency band with path loss exponent $\zeta = 4$ can be set as $\mu = 0$ dB and $\sigma = 9.6$ dB for all u, b and j. Furthermore, On the basis of previous experimental reports in [8] and [9], the shadowing correlation distance on the transmit and receiver sides can be set to 20 m at this frequency band. The detailed simulation parameters are listed in Table 1. Note that, the fading correlation that occurs on both the transmit and receiver sides can be considered as independent because B BSs and U users are geographically separated in general.

Table 1 Simulation parameters

Parameters	Values
Dimensions of rectangular cell	length 400 m width 200 m
Number of subcarriers	$J = 2$
Subcarrier frequency	2.000×10^9 Hz 2.001×10^9 Hz
Number of transmit antennas	$B = 8$
Transmit antenna height	15 m
Number of users	$U = 8$
Number of user samples	100
Path loss exponent	$\zeta = 4$
Shadowing model	spatially correlated
Shadowing cor. in frequency	completely correlated
Shadowing mean value	$\mu = 0$ dB [11]
Shadowing standard deviation	$\sigma = 9.6$ dB [11]
Cor. distance on user side	$d_{\mathrm{cor,r}} = 20$ m [8]
Cor. distance on transmit side	$d_{\mathrm{cor,t}} = 20$ m [9]
SCC parameter	$\kappa = 0.3$ [9]
Number of shadowing samples	200
Rayleigh fading model	spatially correlated
Fading cor. in frequency	mutually independent
Fading spatial cor. on user side	i.i.d. ($\beta_{\mathrm{r}} = 0$)
Fading spatial cor. on transmit side	i.i.d. ($\beta_{\mathrm{t}} = 0$)
Number of fading samples	1000

4.2 Simulation results

In this subsection, we compare the performances of four different types of dynamic CSs, including exhaustive search, the proposed algorithm, norm-based and LOCA algorithm, via the calculation of the CDF and expectation of the system sum rate using a Monte Carlo numerical computation method. Unlike our proposed algorithm, the norm-based algorithm is a suboptimal dynamic CS that selects the user-BS pair corresponding to the row and column of channel gain matrix with the largest Euclidean norm instead of the user-BS pair that maximizes the sum rate.

The LOCA algorithm is a advanced CS compared to the existing location-based algorithm. In latter one, subcarriers are allocated to the users and BSs involved in the communication based on their current location. The geographical area is divided into a cellular structure with each cell having a unique and fixed subcarrier associated with it. Any user and BS located in a given cell will communicate on the subcarrier associated with that cell. The biggest different between this two algorithms is, in LOCA algorithm, the subcarrier associated with its cell may be changing corresponding to every channel realization, not be fixed. Therefore, the CP can maximize the system sum rate by dynamically allocating the subcarriers to appropriate cells during each time slot.

Figures 2 and 3 show comparisons of the CDF and expectation of the sum rate in the OFDM-based MU-MIMO DAS with spatial correlation using exhaustive search, the

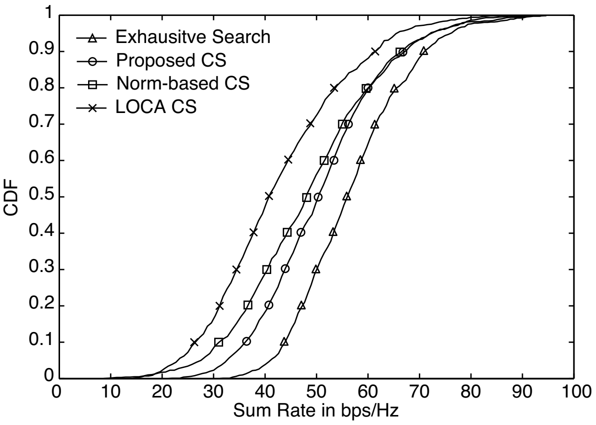

Fig. 2 Comparison of the CDF of the sum-rate using proposed and other CSs for SNR=10 dB.

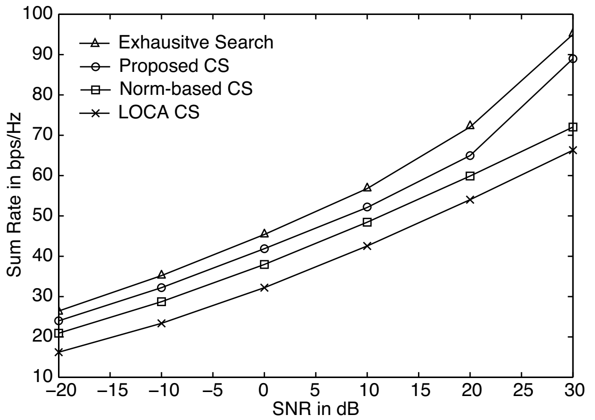

Fig. 3 Comparison of the CDF of the sum-rate using proposed and other CSs.

proposed, norm-based and LOCA dynamic CSs. The CDF is plotted against the system sum rate and the expectation is a function of average receive signal and noise ratio (SNR). It can be seen from these figures that the results obtained using our proposed CS are close to exhaustive search comparing to other CSs, which clearly demonstrates that the proposed algorithm described in Section 3. is effective. This algorithm works because we concentrate on finding the user-BS pairs that maximizes the sum rate instead of the pairs corresponding to the rows and columns of channel gain matrix with the largest Euclidean norm, owing to the sum rate not only dominated by the channel gain matrix but also by the transmit power. This is the main reason that our proposed scheme has better performance than the norm-based scheme. These two figures also show the worst performance in LOCA scheme since this algorithm leads to a lack of diversity with respect to changing channel conditions [4].

5. Conclusion

To establish a wide service area of MU-MIMO DASs, the use of dynamic CS is necessary to reduce a huge amount of computation in precoding. In this study, we proposed a novel algorithm for dynamic clustering by employing a OFDM-based MU-MIMO DAS and investigated its performances by observing the CDF and expectation of the system sum rate. We also compared the characteristics of our proposed CS and other classical dynamic CS, for instance, exhaustive search, norm-based and LOCA algorithm, in terms of sum rate improvement. Moreover, in order to make our results more universality, we further introduced the spatial correlation in considered system, in particular, the spatial correlation in shadowing that exists widely in DASs. Computer simulation results indicated that our proposed CS provide better performance than the existing schemes in the literature and can achieve similar sum rate as the optimal dynamic CS, i.e., exhaustive search, which clearly demonstrates that the proposed CS is effective.

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