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# Sub-channel shared resource allocation for multi-user distributed MIMO-OFDM systems*

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**Abstract:** Well-controlled resource allocation is crucial for promoting the performance of multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) systems. Recent studies have focused primarily on traditional centralized systems or distributed antenna systems (DASs), and usually assumed that one sub-carrier or sub-channel is exclusively occupied by one user. To promote system performance, we propose a sub-channel shared resource allocation algorithm for multi-user distributed MIMO-OFDM systems. Each sub-channel can be shared by multiple users in the algorithm, which is different from previous algorithms. The algorithm assumes that each user communicates with only two best ports in the system. On each sub-carrier, it allocates a sub-channel in descending order, which means one sub-channel that can minimize signal to leakage plus noise ratio (SLNR) loss is deleted until the number of remaining sub-channels is equal to that of receiving antennas. If there are still sub-channels after all users are processed, these sub-channels will be allocated to users who can maximize the SLNR gain. Simulations show that compared to other algorithms, our proposed algorithm has better capacity performance and enables the system to provide service to more users under the same capacity constraints.

**Key words:** MIMO-OFDM, Multi-user, Resource allocation, Sub-channel shared, Signal to leakage plus noise ratio (SLNR)
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## 1 Introduction

During recent years, the distributed multiple input multiple output (MIMO) system, a combination of the distributed antenna system (DAS) and the traditional centralized MIMO system, has become one of the most promising systems for future wireless communications. Compared with DAS and centralized MIMO systems, it has better capacity and cell coverage performance, and is much more robust to shadow fading (Simeone *et al.*, 2009; He *et al.*, 2012; Lu *et al.*, 2012). On the other hand, orthogonal frequency division multiplexing (OFDM) is a well-accepted technique to mitigate the effects of inter-symbol interference in frequency selective channels. Therefore, distributed MIMO-OFDM will become a more competitive choice for future broadband wireless communication systems.

The downlink resource allocation technique is crucial for further promoting data rate of multiple users in multi-antenna OFDM systems. It allocates antennas, sub-carriers, power, bits, etc. to users to maximize the system sum capacity or minimize the overall transmit power under the same constraints, such as user fairness, energy efficiency, or the bit error rate (BER) (Zhu and Wang, 2013). In recent years, a large number of technical publications have been devoted to resource allocation techniques in MIMO-OFDM (Ayad *et al.*, 2011; Chen and Swindlehurst, 2012; Ng and Schober, 2012; Moretti and Perez-Neira, 2013). There are also quite a few algorithms specially designed for distributed antenna

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OFDM systems (Yang and Tang, 2010; He *et al*., 2014). However, they usually assume that one sub-carrier or sub-channel is exclusively occupied by one user, which means they cannot make full use of the space division multiple access (SDMA) in MIMO systems and thus have a capacity-limited performance. Additionally, although both centralized MIMO systems and DAS can be regarded as special cases of distributed MIMO systems, because of the differences between the characteristics of distributed MIMO systems and those of the traditional centralized MIMO systems and DASs, these resource allocation algorithms will not work well in a distributed MIMO system. Therefore, it is necessary to design an algorithm taking the channel and structural characteristics of distributed MIMO systems into account.

This paper focuses on antenna and sub-carrier allocation in the downlink distributed MIMO-OFDM system at the transmitter side, and a sub-channel shared resource allocation algorithm is proposed combining signal to leakage plus noise ratio (SLNR) pre-coding (Sadek *et al*., 2007; Xia *et al*., 2009; Patcharamaneepakorn *et al*., 2012) and resource allocation. To keep the sum channel capacity and low complexity, the algorithm assumes that each user communicates with only two antenna ports, which can take advantage of the multiple ports and reduce the computational complexity and feedback overhead. Each user will select two best ports for communication according to the channel estimation, and feed back the chosen port indices and sub-channel matrices to the base station (BS). Then for each user, the sub-channel will be allocated in descending order, which means one sub-channel that can minimize SLNR loss is deleted until the number of remaining sub-channels is equal to that of receiving antennas. If there are still sub-channels after all users are processed, these sub-channels will be allocated to users who can maximize their SLNR gains. Simulations have shown that the proposed algorithm achieves better performance than those algorithms assuming that one sub-carrier or sub-channel is exclusively occupied by one user.

## 2 System model

In a distributed MIMO system, transmitting antennas are located at different places while receiving antennas are located at the same place or different places. A single user distributed MIMO system is composed of one user with $M$ antennas and $N$ BS antenna ports located far from each other, and there are $L$ antennas at each antenna port. Such a system can be expressed as ($M$, $N$, $L$). DAS and centralized MIMO systems are two special cases of the distributed MIMO system, as the former has only one antenna at each port and the latter has only one port.

We assume that the BS communicates with $K$ users simultaneously, and each user's antenna number is $M_k$ ($k$=1, 2, …, $K$). Such a system can be expressed as ($K$, $\boldsymbol{M}$, $N$, $L$), where $\boldsymbol{M}=[M_1, M_2, \ldots, M_K]^{\mathrm{T}}$ is the user antenna number vector. Fig. 1 shows a sample system of (2, $[2\ 2]^{\mathrm{T}}$, 4, 4).

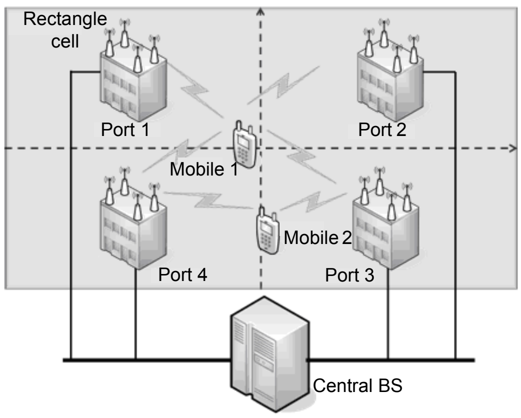


**Fig. 1 A multi-user distributed MIMO system**

A distributed MIMO system becomes a distributed MIMO-OFDM system when OFDM is introduced into the system. Next we will first set up a downlink multi-user distributed MIMO-OFDM system model, and then formulate its sum channel capacity.

### 2.1 Downlink model

A multi-user downlink distributed MIMO-OFDM system model is shown in Fig. 2.

Assume that there are $M_{\mathrm{C}}$ sub-carriers in the system and that $K_P$ ($K_P \le K$) users communicate with antenna port $P$ ($P$=1, 2, …, $N$). The composite fading channel (Liu and Wu, 2007) is frequency selective. The length of cyclic prefix (CP) in OFDM symbols is large enough so that no interference exists between the sub-carriers, and the fading in each sub-carrier is

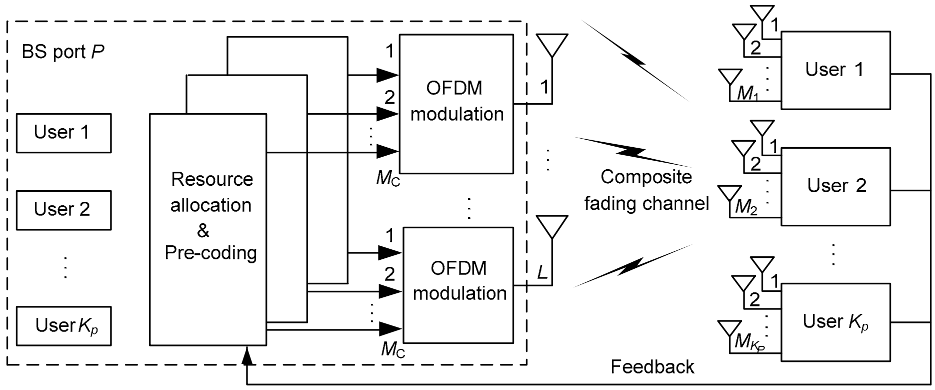


**Fig. 2 System model of multi-user distributed MIMO-OFDM downlink**

flat. Thus, the system transmitting channel can be divided into $M_C N_t$ sub-channels (Sadek *et al.*, 2007), where $N_t$=$NL$.

Assume that a user can ideally obtain the channel state information (CSI) and correctly feed it back to the BS, so that the BS can allocate resource based on the CSI. The co-channel interference (CCI) is decreased via SLNR pre-coding (Sadek *et al.*, 2007).

A user's receiving signal can be expressed as

$$\boldsymbol{r}_m^k = \boldsymbol{H}_m^k \boldsymbol{F}_m^k \boldsymbol{s}_m^k + \boldsymbol{H}_m^k \sum_{i=1, i\neq k}^{K} \boldsymbol{F}_m^i \boldsymbol{s}_m^i + \boldsymbol{z}_m^k, \tag{1}$$

where $\boldsymbol{r}_m^k \in \mathbb{R}^{M_K \times 1}$ is the receiving signal vector, $\boldsymbol{F}_m^k \in \mathbb{R}^{N_t \times t_m^k}$ is the pre-coding matrix, $\boldsymbol{s}_m^k \in \mathbb{R}^{t_m^k \times 1}$ represents the symbols transmitted to user $k$ ($k$=1, 2, …, $K$) on sub-carrier $m$ ($m$=1, 2, …, $M_C$), $\boldsymbol{z}_m^k \in \mathbb{R}^{M_K \times 1}$ is the additional complex Gaussian white noise with $\boldsymbol{z}_m^k$~CN($\boldsymbol{I}$, $\sigma^2$), following the complex Gaussian distribution where $\boldsymbol{I}$ is an identity matrix, and $\boldsymbol{H}_m^k \in \mathbb{R}^{M_K \times N_t}$ is the channel matrix including $N$ independent sub-matrices each with dimension $M_k \times L$:

$$\boldsymbol{H}_m^k = [\boldsymbol{H}_{m,1}^k \; \boldsymbol{H}_{m,2}^k \cdots \boldsymbol{H}_{m,N}^k]. \tag{2}$$

In Eq. (2), $\boldsymbol{H}_{m,i}^k$ is the sub-channel matrix corresponding to antenna port $i$ and is expressed as

$$\boldsymbol{H}_{m,i}^k = [\boldsymbol{h}_{m,i}^{k,1} \; \boldsymbol{h}_{m,i}^{k,2} \cdots \boldsymbol{h}_{m,i}^{k,L}], \tag{3}$$

where $\boldsymbol{h}_{m,i}^{k,l} = \left[ h_{m,i}^{k,1l} \; h_{m,i}^{k,2l} \cdots h_{m,i}^{k,M_k l} \right]^{\mathrm{T}}$. $h_{m,i}^{k,jl}$ is the channel fading between user $k$'s $j$th antenna and port $i$'s $l$th antenna on sub-carrier $m$, including path loss, shadow fading, and small scale fading, and can be calculated as (Liu and Wu, 2007)

$$h_{m,i}^{k,jl} = 10^{-\xi_{m,i}^k/20} (d_i^k / d_{i\min}^k)^{-\alpha/2} h, \tag{4}$$

where $d_i^k$ is the distance between user $k$ and port $i$, and $d_{i\min}^k = \min\{d_i^k\}$ ($i$ = 1, 2 ,..., $N$). $\alpha$ is the path loss factor, $\xi_{m,i}^k \sim N\left(0, (\sigma_{m,i}^k)^2\right)$ is the zero-mean Gaussian variable, $\sigma_{m,i}^k$ is the standard deviation of shadowing between user $k$ and port $i$ on sub-carrier $m$, and $h$~CN(0, 1) is the small scale fading, which follows the complex Gaussian distribution. We assume that the shadow fading on each sub-carrier has the same distribution, i.e., $\sigma_{1,i}^k = \sigma_{2,i}^k = \cdots = \sigma_{M_C,i}^k = \sigma_{\mathrm{sh}}$.

All users share the sub-channels on each sub-carrier. Assume there is no interference between sub-carriers, and CCI is processed through SLNR pre-coding. Then we obtain

$$\mathrm{SLNR}_m^k = \frac{\left\| \boldsymbol{H}_m^k \boldsymbol{F}_m^k \right\|_F^2}{M_k \sigma^2 + \left\| \tilde{\boldsymbol{H}}_m^k \boldsymbol{F}_m^k \right\|_F^2}, \tag{5}$$

where '$\|\cdot\|_F$' represents the Frobenius norm, $\mathrm{SLNR}_m^k$ is the SLNR of user $k$ on sub-carrier $m$ and $\tilde{\boldsymbol{H}}_m^k$ is defined as the leakage channel matrix of user $k$ on sub-carrier $m$ satisfying

$$\tilde{\boldsymbol{H}}_m^k = \left[ \left(\boldsymbol{H}_m^1\right)^{\mathrm{H}} \cdots \left(\boldsymbol{H}_m^{k-1}\right)^{\mathrm{H}} \left(\boldsymbol{H}_m^{k+1}\right)^{\mathrm{H}} \cdots \left(\boldsymbol{H}_m^K\right)^{\mathrm{H}} \right]^{\mathrm{H}}. \quad (6)$$

If the BS transmits only one data stream to each user on each sub-carrier, namely $t_m^k = 1$, there is

$$\boldsymbol{F}_m^k \propto \text{max eigenvector} \, \boldsymbol{A}_m^k, \quad (7)$$

$$\boldsymbol{A}_m^k = \left[ \left(\tilde{\boldsymbol{H}}_m^k\right)^{\mathrm{H}} \tilde{\boldsymbol{H}}_m^k + M_k \sigma^2 \boldsymbol{I} \right]^{-1} \left(\boldsymbol{H}_m^k\right)^{\mathrm{H}} \boldsymbol{H}_m^k. \quad (8)$$

Eq. (7) means that $\boldsymbol{F}_m^k$ is the eigenvector corresponding to the maximum eigenvalue of $\boldsymbol{A}_m^k$.

### 2.2 Sum channel capacity

According to the model above, the signal to interference plus noise ratio (SINR) of user $k$ on sub-carrier $m$ can be calculated by

$$\mathrm{SINR}_m^k = \frac{\left\| \boldsymbol{H}_m^k \boldsymbol{F}_m^k \right\|_F^2}{M_k \sigma^2 + \sum_{i=1, i \neq k}^{K} \left\| \boldsymbol{H}_m^k \boldsymbol{F}_m^i \right\|_F^2}. \quad (9)$$

The multi-user distributed MIMO-OFDM system sum capacity, which is the sum of all users' capacities, can be expressed as

$$C = \frac{1}{M_{\mathrm{C}}} \sum_{m=1}^{M_{\mathrm{C}}} \sum_{k=1}^{K} \log_2 \left(1 + \mathrm{SINR}_m^k\right). \quad (10)$$

## 3 Previous work

Existing resource allocation algorithms can be divided into two categories: sub-carrier impropriated and sub-channel impropriated. Generally, they both assume that there is no interference between sub-carriers and that users can ideally detect the signal; accordingly, it is not necessary to take the interference signal from other antennas into account. If sub-carriers are allocated with equal power, the maximum transmitting rate of user $k$ on sub-carrier $m$ of the $n$th ($n$=1, 2, …, $N$) antenna can be calculated by (Mielczarek and Krzymien, 2004)

$$R_{m,n}^k = \log_2 \left( 1 + \frac{P_{\mathrm{T}}}{\sigma^2 M_{\mathrm{C}} N_{\mathrm{t}}} \left\| [\boldsymbol{H}_m^k]_n \right\|_F^2 \right), \quad (11)$$

where $P_{\mathrm{T}}$ is the total transmitting power, and $\sigma^2$ is the noise variance of each receiving antenna. If the average SNR of sub-carriers is defined as $\Gamma_{\mathrm{T}}=P_{\mathrm{T}}/(M_{\mathrm{C}}\sigma^2)$, Eq. (11) can be rewritten as

$$R_{m,n}^k = \log_2 \left( 1 + \frac{\Gamma_{\mathrm{T}}}{N_{\mathrm{t}}} \left\| [\boldsymbol{H}_m^k]_n \right\|_F^2 \right), \quad (12)$$

where $[\boldsymbol{H}_m^k]_n$ is the $n$th column of $\boldsymbol{H}_m^k$.

### 3.1 Sub-carrier impropriated algorithms

Let $\rho_m^k \in \{0, 1\}$ be the allocation flag of sub-carrier $m$, $\rho_m^k = 1$ and $\rho_m^k = 0$ mean that sub-carrier $m$ is allocated to user $k$ or not respectively. The problem of a sub-carrier impropriated resource allocation can be denoted by

$$\max_{\rho_m^k} \sum_{k=1}^{K} \sum_{m=1}^{M_{\mathrm{C}}} \sum_{n=1}^{N_{\mathrm{t}}} \rho_m^k \log_2 \left( 1 + \frac{\Gamma_{\mathrm{T}}}{N_{\mathrm{t}}} \left\| [\boldsymbol{H}_m^k]_n \right\|_F^2 \right)$$

$$\text{s.t.} \sum_{k=1}^{K} \rho_m^k = 1, \rho_m^k \in \{0, 1\}, \forall m \in \{1, 2, ..., M_{\mathrm{C}}\}. \quad (13)$$

This restriction means every sub-carrier will be exclusively occupied by one user during one resource allocation time slot. The optimal solution is to do $K^{M_{\mathrm{C}}}$ searches, whose complexity is very high in case of many users and sub-carriers. A sub-optimal method is to calculate the maximum rate of each user on every sub-carrier, and then allocate the sub-carrier to the user who has the maximum rate on this sub-carrier. This sub-optimal method will be chosen for comparison in the simulation.

### 3.2 Sub-channel impropriated algorithms

Sub-channel ($m$, $n$) is determined by sub-carrier $m$ and antenna $n$. $\mu_{m,n}^k \in \{0, 1\}$ is defined as the allocation flag of sub-channel ($m$, $n$), which has the same meaning as $\rho_m^k \in \{0, 1\}$. The problem of a sub-channel impropriated resource allocation algorithm can be denoted by

$$\max_{\mu_{m,n}^k} \sum_{k=1}^{K} \sum_{m=1}^{M_{\mathrm{C}}} \sum_{n=1}^{N_{\mathrm{t}}} \mu_{m,n}^k \log_2 \left( 1 + \frac{\Gamma_{\mathrm{T}}}{N_{\mathrm{t}}} \left\| [\boldsymbol{H}_m^k]_n \right\|_F^2 \right)$$

$$\text{s.t.} \sum_{k=1}^{K} \mu_{m,n}^{k} = 1,\ \mu_{m,n}^{k} \in \{0, 1\},$$
$$\forall m \in \{1, 2, ..., M_{\mathrm{C}}\},\ n \in \{1, 2, ..., N_{\mathrm{t}}\}. \tag{14}$$

This restriction means each sub-channel will be exclusively occupied by one user during one resource allocation time slot. The optimal solution is to do $K^{M_{\mathrm{C}}N_{\mathrm{t}}}$ searches, which is much more complex than sub-carrier impropriated algorithms, making it hard to implement. Accordingly, a sub-optimal algorithm was proposed by Yang and Tang (2010). It allocates the sub-channel to the user who has the maximum rate on this sub-channel. If there are still sub-channels after all users are allocated, these sub-channels will be allocated to users who have the minimum data rate.

## 4 Proposed resource allocation algorithm

A sub-channel shared resource allocation algorithm is presented in this section. We first point out the problems and corresponding solutions, then explain the algorithm's designing process, next give the detailed algorithm steps, and finally discuss the merits of the proposed algorithm.

### 4.1 Questions and solutions

With sub-channels shared by all users, different sub-channels are allocated to users according to their channel states. Meanwhile, SLNR pre-coding is exploited to restrain CCI and power resource allocation is optimized, both of which can promote the system's overall performance. However, from Eqs. (6)–(8), it can be seen that the number of columns of the user channel matrix $\boldsymbol{H}_m^k$ ($k$=1, 2, …, $K$) has to be consistent, which is difficult to obtain during the allocation process because of different allocated sub-channels caused by different channel fading.

Consequently, in this study those columns corresponding to the user's un-allocated sub-channels are substituted with zero vectors. The substituted sub-channels will not afterwards work in a signal transmission, and have no impact on the formation of the receiving data. It is equal to not allocating these sub-channels to the user, which maintains the consistency of the channel columns.

### 4.2 Algorithm design

Theoretically, the optimal sub-channel shared resource allocation algorithm has to run through all possible sub-channel combination to obtain the optimal allocation scheme, which needs $\left(\sum_{i=1}^{K} C_K^i\right)^{M_{\mathrm{C}}N_{\mathrm{t}}}$ searches. Additionally, users have to feed back CSI on all sub-carriers of this search. The high computational complexity and feedback overhead make it unbearable in real systems.

The norm-based resource allocation algorithm is a simple method. Frobenius norm ($F$-norm) is chosen as the basis to estimate all users' current channel states. The same number of sub-channels with user's antennas will be allocated to users on each sub-carrier. If there are still sub-channels after all users being processed, the sub-channels will be allocated to users in descending order according to the $F$-norm. Although the complexity has been decreased, all the CSI still needs to be fed back.

Considering the structural and channel characteristics of the distributed MIMO-OFDM system, antennas belonging to the same port have similar fading states on each sub-carrier. If ports with poor channel states are eliminated when allocating sub-channels, both the complexity and feedback overhead will be reduced. The proposed algorithm is described as follows.

First, each user selects communication ports on each sub-carrier. Assume the selected port number of user $k$ is $P_m^k$. For port $i$ ($i$=1, 2, …, $N$), calculate

$$\mathrm{Trace}_{m,i}^{k} = \mathrm{Tr}\left(\left(\boldsymbol{H}_{m,i}^{k}\right)^{\mathrm{H}} \boldsymbol{H}_{m,i}^{k}\right), \tag{15}$$

and select $P_m^k$ ports with larger trace values, and feed back their indices and corresponding channel submatrices to the BS. To reduce the complexity and feedback overhead while guaranteeing the advantage of multiple ports, we assume $P_m^k = 2$.

Having received feedback information, the BS allocates sub-channels to users in descending order on each sub-carrier. For each user, SLNR loss is minimized due to the selected sub-channels. Column vectors corresponding to these sub-channels are substituted by zero vectors. The detailed method is described as follows.

Let $\boldsymbol{H}_m'^k \in \mathbb{R}^{M_K \times N_t}$ be the restoring channel matrix on sub-carrier $m$ at the BS according to user $k$'s feedback information, including $P_m^k$ sub-channel matrices and $N-P_m^k$ zero matrices. Define $\boldsymbol{H}_{m,j}'^k$ as the channel matrix of user $k$ at the $j$th ($1 \le j \le P_m^k L - N_m^k$) allocation step. $N_m^k$ is the number of user $k$'s allocated sub-channels, $\boldsymbol{h}_{m,j,l}^k$ is the $l$th ($1 \le l \le P_m^k L - j$) non-zero column vector of $\boldsymbol{H}_{m,j}'^k$, and $\tilde{\boldsymbol{H}}_m'^k$ is user $k$'s leakage channel matrix, which can be denoted as

$$\tilde{\boldsymbol{H}}_m'^k = \left[ \left(\hat{\boldsymbol{H}}_m'^1\right)^{\mathrm{H}} \cdots \left(\hat{\boldsymbol{H}}_m'^{(k-1)}\right)^{\mathrm{H}} \left(\boldsymbol{H}_m'^{(k+1)}\right)^{\mathrm{H}} \cdots \left(\boldsymbol{H}_m'^K\right)^{\mathrm{H}} \right]^{\mathrm{H}}, \tag{16}$$

where $\hat{\boldsymbol{H}}_m'^k$ is the new channel matrix of user $k$ after sub-channel allocation. The SLNR value of user $k$ at the $j$th allocation step is

$$\begin{aligned} &\mathrm{SLNR}_{m,j}^k \\ &= \max \text{ eigenvalue}\left[ \left( \left(\tilde{\boldsymbol{H}}_m'^k\right)^{\mathrm{H}} \tilde{\boldsymbol{H}}_m'^k + M_k \sigma^2 \boldsymbol{I} \right)^{-1} \right. \\ &\qquad \left. \cdot \left(\boldsymbol{H}_{m,j}'^k\right)^{\mathrm{H}} \boldsymbol{H}_{m,j}'^k \right], \end{aligned} \tag{17}$$

where max eigenvalue($\boldsymbol{A}$) denotes the maximum eigenvalue of matrix $\boldsymbol{A}$.

Define the SLNR loss caused by substituting $\boldsymbol{h}_{m,j,l}^k$ with a zero vector at the ($j$+1)th step as

$$\varDelta_{j+1} = \mathrm{SLNR}_{m,j}^k - \mathrm{SLNR}_{m,j,l}^k, \tag{18}$$

where $\mathrm{SLNR}_{m,j,l}^k$ is the SLNR value after $\boldsymbol{h}_{m,j,l}^k$ is substituted by zero vectors. To keep $\varDelta_{j+1}$ as small as possible, we just substitute the $\hat{l}$th non-zero vector of $\boldsymbol{H}_{m,j}'^k$ with a zero vector to satisfy

$$\hat{l} = \arg\max_{l} \mathrm{SLNR}_{m,j,l}^k. \tag{19}$$

If there are still sub-channels after all users have been processed, to make full use of system resource, those sub-channels should be allocated as follows. Assume that the summation of all users' SLNR on sub-carrier $m$ is

$$\mathrm{SLNR}_m = \sum_{i=1}^{K} \mathrm{SLNR}_m^i. \tag{20}$$

If the un-allocated sub-channel ($m$, $n$) is assigned to user $k$, the SLNRs of all users will change. Denote the changed summation of all users' SLNR on sub-carrier $m$ as $\mathrm{SLNR}'_{m,k}$, and define SLNR summation gain as $\varSigma_m^k$. The following equation will be established:

$$\varSigma_m^k = \mathrm{SLNR}'_{m,k} - \mathrm{SLNR}_m. \tag{21}$$

Sub-channel ($m$, $n$) will be allocated to user $\hat{k}$ according to

$$\hat{k} = \arg\max_{k} \Sigma_m^k. \tag{22}$$

### 4.3 Algorithm steps

Assume all users' combined channel matrix on sub-carrier $m$ is $\boldsymbol{H}_m\left(\sum_{i=1}^{K} M_i \cdot N_t\right)$. Here we have $\boldsymbol{H}_m = \left[ \left(\boldsymbol{H}_m^1\right)^{\mathrm{H}} \left(\boldsymbol{H}_m^2\right)^{\mathrm{H}} \cdots \left(\boldsymbol{H}_m^K\right)^{\mathrm{H}} \right]^{\mathrm{H}}$. If $[\boldsymbol{H}_m]_n$ is a zero vector, sub-channel ($m$, $n$) is not allocated to users. The sub-channel shared resource allocation algorithm can be described as follows:

Step 1: The BS broadcasts pilot symbols periodically.

Step 2: Users obtain channel matrix $\boldsymbol{H}_m^k$ ($m$=1, 2, …, $M_C$; $k$=1, 2, …, $K$) through channel estimation, select antenna ports according to Eq. (15), and feed back the corresponding port indices and channel matrices to the BS.

The BS allocates sub-channels for each user and takes the following steps:

Step 3: The BS restores the channel matrices $\boldsymbol{H}_m'^k$ ($m$=1, 2, …, $M_C$; $k$=1, 2, …, $K$) according to the feedback information, and supposes $\boldsymbol{H}_m^k = \boldsymbol{H}_m'^k$ and $m$=$k$=$l$=1.

Step 4: Obtain leakage channel matrix $\tilde{\boldsymbol{H}}_m'^k$, $N_m^s = P_m^k L$ according to Eq. (16).

Step 5: If $\boldsymbol{h}_{m,l}^k$, the $l$th column of $\boldsymbol{H}_m'^k$, is a non-zero vector, go to the next step; if $l$ equals $N_t$, go to step 7; else let $l=l+1$ and repeat this step.

Step 6: Set $\boldsymbol{h}_{m,l}^k$ to a zero vector and compute $\text{SLNR}_{m,l}^k$ according to Eq. (17). If $l$ equals $N_t$, go to the next step; else let $l=l+1$ and go to step 5.

Step 7: Update parameters and set the $\hat{l}$th column of $\boldsymbol{H}_m'^k$ to a zero vector according to Eq. (19), $N_m^s = N_m^s - 1$. If $N_m^s$ is not equal to $N_m^k$, let $l=1$ and go to step 5; if $k$ equals $K$, go to the next step; else let $k=k+1$ and go to step 4.

Step 8: Update $\tilde{\boldsymbol{H}}_m'^k$, calculate the $\text{SLNR}_m^k$ ($1 \le k \le K$) and $\text{SLNR}_m$ according to Eq. (20), and let $n=1$.

Step 9: Construct user combined channel matrix $\boldsymbol{H}_m$ according to $\boldsymbol{H}_m'^k (k = 1, 2, \cdots, K)$. If $\boldsymbol{h}_{m,n}$, the $n$th column of $\boldsymbol{H}_m$, is a zero vector then let $k=1$ and go to the next step; if $n$ is equal to $N_t$, go to step 13; else let $n=n+1$ and repeat this step.

Step 10: If the $n$th column of $\boldsymbol{H}_m^k$ is not a zero vector, go to the next step; if $k$ is equal to $K$, go to step 12; else let $k=k+1$ and repeat step 10.

Step 11: Substitute the zero vector of $\boldsymbol{H}_m'^k$ with the $n$th column of $\boldsymbol{H}_m^k$ and compute $\text{SLNR}_{m,k}'$ according to Eq. (20). If $k$ is equal to $K$, go to the next step; else let $k=k+1$ and go to step 10.

Step 12: Update parameters and allocate sub-channel ($m$, $n$) to user $\hat{k}$ according to Eq. (22), and then update $\hat{\boldsymbol{H}}_m'^k$. If $n$ equals $N_t$, go to the next step; else go to step 9.

Step 13: If $m$ equals $M_C$, go to the next step; else let $m=m+1$, $k=1$, and go to step 4.

Step 14: Compute $\boldsymbol{F}_m^k$ ($m=1, 2, \ldots, M_C$; $k=1, 2, \ldots, K$) according to Eq. (7), and compute the system sum capacity according to Eqs. (9) and (10).

Among the steps above, step 2 corresponds to the port selection of users; steps 3–8 correspond to the initialization of allocation of the sub-channel allocation process, during which all users are allocated the same number of sub-channels with receiving antennas; and steps 9–12 correspond to the remaining sub-channel allocation process in which the remaining sub-channels are allocated to the users that can maximize the SLNR gain.

### 4.4 Algorithm analysis

As a whole, the merits of the proposed algorithm are as follows:

1. Good use is made of the structural characteristics of the distributed MIMO-OFDM systems. The algorithm fits the system well. It not only takes advantages of multiple ports by selecting two ports for each user to communicate with, but also efficiently reduces the complexity and feedback overhead in the process of resource allocation.

2. More freedom in resource allocation can be provided. Different from existing sub-carrier impropriated and sub-channel impropriated algorithms, the proposed algorithm allows multiple users to share the same sub-channel, which may result in better performance.

3. The CCI caused by sharing sub-channels can be decreased. SLNR pre-coding and resource allocation are combined by allocating sub-channels based on the SLNR criterion in the proposed algorithm, which may efficiently promote the performance.

## 5 Simulation results

In this section, we compare the performance of the proposed algorithm with that of other algorithms including a sub-optimal sub-carrier impropriated algorithm (an algorithm based on orthogonal frequency division multiple access (OFDMA), mentioned in Section 3.1), Yang's algorithm (Yang and Tang, 2010), a norm-based resource allocation algorithm, a sub-channel shared algorithm exploiting only SLNR pre-coding, and an algorithm based on time division multiple access (TDMA). The algorithm based on TDMA randomly selects only one user for each time slot and allocates all system resources to it. From Eq. (4), we can see that due to the normalization of the distance vectors, factors such as the number and distribution of the antenna ports, cell shape, and coverage, would not affect the rough value range of the channel matrix under the condition of random user terminal distributions; therefore, the evaluation of the algorithm performance would not be influenced. Thus, the scenario in Fig. 1 is considered. Simulation parameters are listed in Table 1.

Fig. 3 shows the capacity performance versus the sub-carrier SNR. It shows that sub-channel shared algorithms have much better performance than sub-channel and sub-carrier impropriated algorithms. The main reason is that the former can make full use of spatial diversity and provide a much more flexible resource allocation. The proposed algorithm is the best one among the three sub-channel shared algorithms mentioned. Different sub-channels allocated to users can, to some extent, decrease users' transmitting signal on the same sub-carrier, which can reduce CCI. Additionally, allocating a sub-channel based on SLNR and SLNR pre-coding is more reasonable for sub-channel utilization and can more efficiently restrain interference.

Fig. 4 shows user's average rate versus the number of transmitting antennas. It shows that Yang's algorithm has better performance when the number of receiving antennas is much larger than that of transmitting antennas (e.g., $N_r$=2×10=20 and $N_t$=4). Although sub-channel allocation and SLNR pre-coding can reduce CCI, the remaining CCI can still degrade system performance. With an increasing number of transmitting antennas, the performance improvement of sub-channel and sub-carrier impropriated algorithms slows down as they are restricted by the transmitting power and exclusive criterion, while the performance of sub-channel shared algorithms improves quickly with larger sub-channel allocation optimization space.

**Table 1 Simulation parameters**

| Simulation parameter | Value |
|---|---|
| Cell area | 1000×1000 m$^2$ |
| Antenna port number | 4 |
| Antenna number per port | 4 |
| Location of antenna port | Center of each small square |
| User distribution | Uniformly distributed in the whole square |
| User antenna number | 2 |
| Sub-carrier number | 64 |
| Channel type | Composite fading channel |
| Path loss factor | 4 |
| Shadow fading standard variable | 8 dB |
| Small scale fading | Rayleigh fading |
| Separable path number of small scale fading | 6 |
| Capacity performance metric | Average sum rate per user or sum capacity |

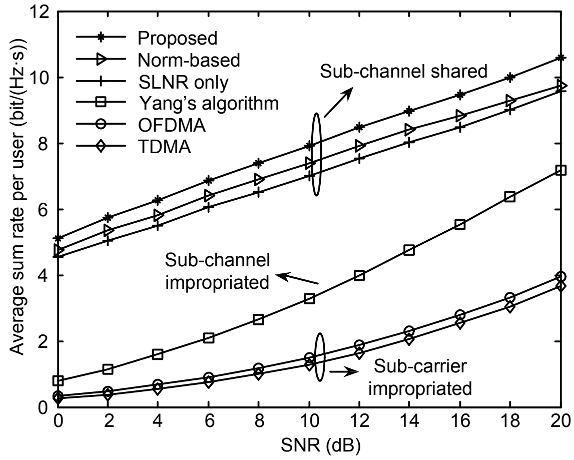


**Fig. 3 Average sum rate per user versus SNR with eight users in the system**

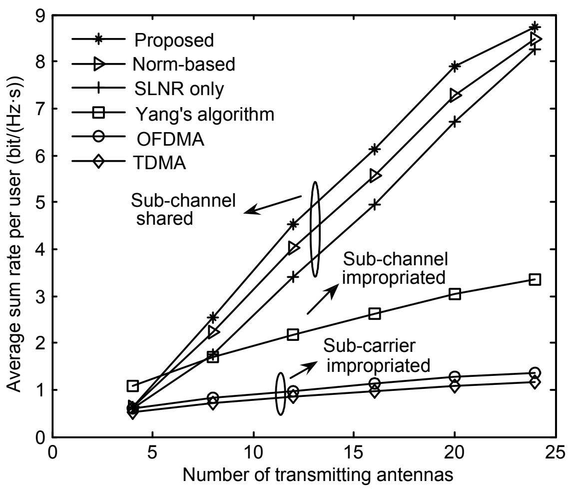


**Fig. 4 Average sum rate per user versus the number of transmitting antennas with an SNR of 10 dB and 10 users in the system**

Fig. 5 shows user's average rate versus the number of users. When there is a small number of users, the three sub-channel shared algorithms have similar performance and are all much better than sub-channel and sub-carrier impropriated algorithms. The advantage becomes less when the number of users increases. The sub-channel shared algorithm exploiting only the SLNR pre-coding algorithm is worse than Yang's algorithm when the number of users increases to some extent. When there is a small number of users, system resource is abundant for the sub-channel shared algorithm to exploit more efficiently. It does not work to slow down the deterioration in system performance only by SLNR pre-coding with a rapid increase of CCI caused by increasing the number of users.

Fig. 6 shows the system sum capacity versus the number of users. When the number of users increases, the three sub-channel shared algorithms' system sum capacities increase first and then decrease. The maximum sum capacity of the proposed algorithm is the largest one among them, which means that by exploiting the proposed algorithm, the system can accommodate more users under the same capacity constraint. SLNR pre-coding and allocating different sub-channels, which are exploited by the proposed algorithm, can both reduce CCI. Allocating sub-channels based on SLNR is more reasonable than that based on norm. In conclusion, the proposed algorithm has better performance.

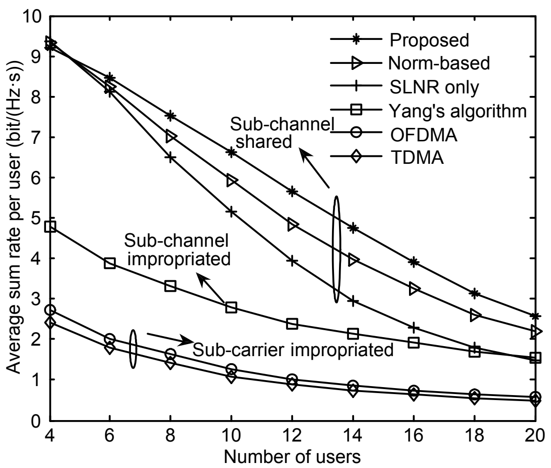


**Fig. 5 Average sum rate per user versus the number of users with an SNR of 10 dB**

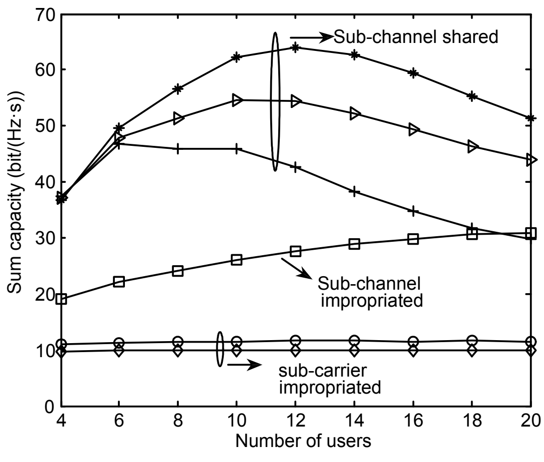


**Fig. 6 Sum capacity versus the number of users with an SNR of 10 dB**

## 6 Conclusions

This paper proposes a sub-channel shared resource allocation algorithm for a downlink distributed MIMO-OFDM system, which allows each sub-channel to be shared by multiple users. It partially reduces the computational complexity and feedback overhead through port selection, allocates different sub-channels to users, and exploits SLNR pre-coding to suppress CCI caused by sharing sub-channels. During the allocation process, each sub-carrier is allocated to users in descending order based on the SLNR criterion. For each user, one sub-channel that can minimize SLNR loss is deleted until the number of remaining sub-channels is equal to the number of receiving antennas. If there are still sub-channels after all users are processed, these sub-channels will be allocated to the users who can maximize the SLNR gain. Simulations show that the proposed algorithm has better capability performance, and can accommodate more users under the same capability constraint. Note that the proposed algorithm is suitable only for a single cell scenario, and future work is to consider it in coordinated multiple point (CoMP) transmission surroundings.

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