Abstract To minimize transmitting power, an adaptive resource allocation algorithm is proposed for multi-user multiple input multiple output-orthogonal frequency division multiplexing (MIMO-OFDM) downlink with correlated channels, which, based on the user’s grouping according to their spatial correlations, combines the shared manner and the exclusive manner to allocate sub-carriers. Between different groups the shared manner with a null steering method based on group marginal users is applied, whereas within a group the exclusive manner is applied. The simulations show that the power efficiency and spectral efficiency are improved; the base station transmitting antenna number and the computational complexity is decreased.

Keywords MIMO-OFDM, multi-user, adaptive resource allocation, co-channel interference (CCI), null steering

1 Introduction

Adaptive resource allocation for multi-user multiple input multiple output-orthogonal frequency division multiplexing (MIMO-OFDM) system can improve its power efficiency and spectral efficiency [1]. The allocation includes two classes, i.e., the exclusive manner and the shared manner to sub-carrier. The exclusive manner is easily realized with low spectral efficiency. While the shared manner has high spectral efficiency, the co-channel interference (CCI) is introduced by the spatial multiplexing of different users on the same sub-carrier. Moreover, its performance is affected by user spatial correlation, antenna number and computation complexity [2,3]. Reference [4] proposes a zero forcing (ZF) algorithm at the base station (BS) to mitigate CCI, but it does not consider the impact of user spatial correlation and computation complexity.

This research proposes a resource allocation algorithm for MIMO-OFDM downlink in correlated channels, which combines the exclusive manner and the shared manner based on the grouping of users according to their spatial correlations. The algorithm improves the system performance and reduces both the transmitting antenna number and the computational complexity.

2 System model

In this paper, an outdoor downlink adaptive multi-user MIMO-OFDM system equipped with $N_c$ sub-carriers, $n_T$ transmitting antennas at the BS and $n_R$ receiving antennas for each of $K$ users is considered. Each sub-carrier can be considered as a Rayleigh flat fading channel and the fading is correlated at the transmitter side, but it is uncorrelated at the receiver side [5]. In this case, the channel for user $k$ ($k = 1, 2, ..., K$) in the sub-carrier $m$ ($m = 1, 2, ..., N_c$) can be modeled as

$$ H^k_m = G^k_m A^k_m = \begin{bmatrix} h^k_{1,1} & h^k_{1,2} & \cdots & h^k_{1,n_T} \\ h^k_{2,1} & h^k_{2,2} & \cdots & h^k_{2,n_T} \\ \vdots & \vdots & \ddots & \vdots \\ h^k_{n_R,1} & h^k_{n_R,2} & \cdots & h^k_{n_R,n_T} \end{bmatrix}, $$

where $G^k_m$ is an $n_R \times D_k$ matrix with zero-mean unit-variance i.i.d complex Gaussian entries; $A^k_m$ is the steering matrix of size $D_k \times n_T$ that contains $D_k$ steering vectors of the transmitting antenna array, i.e., $D_k$ directions of departure (DOD); $h^k_{i,j}$ is the channel gain from the $j$th transmitting antenna to the $i$th receiving antenna. We assume that the perfect channel state information (CSI) is known to the BS and the receiver. For a uniform linear array, the steering matrix $A^k_{nm}$ is given by
where $T$ represents the transpose operation, $d$ is the equivalent antenna spacing, $\lambda$ is the carrier wavelength, and $\theta$ is the DOD. $\theta_k$ denotes the main angle of DOD for the user $k$, and $\Delta \psi_k$ is the angle spread, then $\theta_{kD_k} = \theta_k + \rho \Delta \psi_k$, $\rho \in [-1, 1]$. We define $\mathbf{d}_m$, $\mathbf{w}_m$, $\mathbf{R}_m$, and $\mathbf{y}_m$ as the transmitting complex symbol, the transmitting beamforming vector, the weighted combining vector, and the receiving complex symbol vector for the $k$th user on the $m$th sub-carrier, respectively. Then, $\mathbf{y}_m$ can be formulated as follows:

$$
\mathbf{y}_m = \mathbf{H}_m^k \mathbf{w}_m^k \mathbf{d}_m^k + \sum_{j=1,j \neq k}^{K} \mathbf{H}_m^k \mathbf{w}_m^j \mathbf{d}_m^j + \mathbf{n}_m^k 
$$

where the first item on the right side of Eq. (3) represents the received symbols from the desired user, the second represents the CCI from the interference users, and $\mathbf{n}_m^k$ is a noise vector.

After weighted combining, the received symbol is given by

$$
\hat{\mathbf{d}}_m = \mathbf{R}_m^k \mathbf{H}_m^k \mathbf{w}_m^k \mathbf{d}_m^k + \sum_{j=1,j \neq k}^{K} \mathbf{R}_m^k \mathbf{H}_m^k \mathbf{w}_m^j \mathbf{d}_m^j + \mathbf{R}_m^k \mathbf{n}_m^k. 
$$

The key of demodulation is that the CCI is mitigated and the linear processing is achieved at both the transmitter and the receiver by properly choosing $\mathbf{R}_m^k$ and $\mathbf{w}_m^k$. The optimal problem of minimizing the overall transmitting power is formulated as follows:

$$
\arg \min_{\mathbf{b}_m^k} \sum_{m=1}^{N_c} \sum_{k=1}^{K} P_m^k, \\
\text{subject to: } \sum_{m=1}^{N_c} b_{m}^k = R_k, \\
\text{BER}_m^k \leq \text{BER}_{\text{target}}. 
$$

The transmitting power of the shared user can be described as

$$
P_m^k = g\left(\text{BER}_{\text{target}}, b_{m}^k, \{\mathbf{H}_m^{k'}\}_{k'=1,...,K}\right),
$$

$$
\{P_m^k\}_{k'=1,...,k-1,k+1,...,K}. 
$$

We can see that the transmitting power of different users is interrelated owing to the CCI. This makes the optimal problem very complex. The CCI can be removed by the exclusive manner or the ZF shared manner. The transmitting power of the shared user turns into

$$
P_m^k = g\left(\text{BER}_{\text{target}}, b_{m}^k, \{\mathbf{H}_m^{k'}\}_{k'=1,...,K}\right). 
$$

Thus, the complexity of multi-user resource allocation is reduced. However, the two manners have different performances for different user spatial correlations.

### 3 System performance and user spatial correlation

As the angle spread of DOD is usually slight, the spatial correlation coefficient between the users can be denoted by $\theta$ as follows:

$$
\rho_{k1,k2}^m = \begin{cases} 
\frac{1}{nT} & \exp\left(j2\pi\frac{d}{\lambda}\left(\sin \theta_{k1} - \sin \theta_{k2}\right)\right), \theta_{k1} \neq \theta_{k2}, \\
1, & \theta_{k1} = \theta_{k2}.
\end{cases}
$$

Thus, it can be adjusted by varying $\theta$ of the users. Two users are highly correlated when the angle between them is less than $5^\circ$.

Two allocation manners are simulated for a two-user system with $d = \lambda/2$, $n_T = 4$, $n_R = 2$, $\theta_{k1} = 0^\circ$, $\text{BER} = 10^{-3}$, 64 sub-carrier, on average 3 bits per sub-carrier for each user. Figure 1 plots $\text{E}_b/\text{N}_0$ versus $\theta_{k2}$ curves. It demonstrates that the power required of the exclusive manner is not affected by $\theta_{k2}$, but the performance is not optimal with low user spatial correlation. The power of the ZF shared