Resource Allocation and Minimum Rate for Precoded Non-orthogonal Multiple Access

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***Abstract*—In this paper, we propose user clustering and power allocation algorithms for a precoded NOMA system. The user clustering for the strong and the weak users, and corresponding power allocation can be optimized disjointedly when SNR is sufficiently high, and this leads to a great reduction in computational complexity. Moreover this proposed power allocation algorithm can maximize sum achievable rate subject to a minimum target rate. Furthermore, from the analytical results, we suggest a reasonable minimum target rate for the weak user so that this rate can always be achieved, *i.e,* with outage probability 1. Using the suggested target rate, the NOMA system can avoid failing in achieving this target rate even if all power is allocated to the weak user. Simulation results corroborate theoretical results.**

I. Introduction

Non-orthogonal multiple access (NOMA) has been widely studied for the fifth generation (5G) wireless communications, because it enhances spectrum efficiency and improves sum achievable rate [1]-[3]. Unlike orthogonal multiple access (OMA), NOMA allows to transmit signals of multiple users in the same time frame and frequency band via different power levels. The superposed signals of multiple users can be decoded using successive interference cancellation (SIC) [1],[3].

The number of transmit antennas is usually smaller than the number of total receive user antennas in NOMA, *i.e.,* an overloaded technique, and this results in multiuser interference. To reduce interference and improve the sum achievable rate, careful resource allocation including user clustering and power allocation shall be applied [3]-[5]. More specifically, the authors in [3] and [4] suggested that users with high channel correlations and high difference of channel gain shall be clustered. In [5], the authors proposed a channel state sorting-pairing algorithm (CSS-PA) based on the results of channel state sorting, which clusters a good channel-condition user with a poor channel-condition user. Furthermore, a power allocation scheme for NOMA systems have been studied to maximize sum-rate while keeping the achievable rate of the weak user be equal to that in conventional case in [3].

To maximize sum rate, the optimal solution for user clustering and power allocation shall be done jointly via exhaustive search. However, this demands huge computational complexity. Moreover, in the NOMA system, a minimum target rate is usually constrained for the weak user in a cluster for achieving a target QoS (quality of service). A reasonable target rate is important, because if the target rate is too high, there is little chance that the weak user can achieve this rate even if all power has been allocated to this weak user. When this happens, some bad situations occur including 1) the system spends a lot of power to the weak user but still the requirement cannot be attained, and this significantly decreases the sum achievable rate because the strong user generally dominates the sum achievable rate but few power has been allocated to him/her; 2) NOMA returns to conventional MU-MIMO due to the failure of achieving the requirement of the minimum target rate. These motivate us to investigate complexity-reduced resource allocation schemes as well as find out reasonable target rate for the weak users.

In this paper, we propose a clustering algorithm for strong and weak users. We notice that the sum rate is usually dominated by the strong users because they do not receive inter- and intra-cluster interference when SIC and block diagonalization precoding are applied. Thus we suggest to select strong users by the semiorthogonal user group (SUS) algorithm [6] to orthogonalize channels. Consequently, high multiuser sum rate of strong users can be achieved. Then the weak users are selected by maximizing the multiuser sum rate, in which both inter- and intra-cluster interference appear. At the first glance, exhaustive search shall be used to select the weak users. In this work, we prove that when SNR is sufficiently high, searching exhaustively for maximizing sum rate can be replaced simply by finding the weak users whose channels have similar directions with those of the strong users, and interestingly this searching is irrelevant to the power allocation scheme. Hence, the optimization problem for user clustering and power allocation can be solved separately. As a result, computational complexity can be significantly reduced. Moreover, subject to a power constraint and a minimum achievable target rate, we propose an optimal power allocation for achieving the maximum sum rate. Furthermore, we provide a closed-form solution for the outage probability of a specific target rate that the weak user can achieve. This solution can be used to suggest a reasonable target rate for the weak user. Since different parameters such as number of total users, number of clusters and SNR affect the reasonable target rate, the proposed solution provides a good reference design in practical precoded NOMA systems.

II. System Model and Problem Formulation

A block diagram of the proposed NOMA system is shown in Fig. 1. There are N antennas at base station and K

single-antenna users ($K \geq 2N$). Each one of the N transmit precoding vectors can support two or more users instead of only one user. In this study, we assume that two users are grouped into a cluster for the sake of simplicity. In this case, $2N$ users are selected out of K users, and they are supported by N precoding vectors. In each of the the N clusters, the two users are labeled as strong user and weak user according to their channel gains.

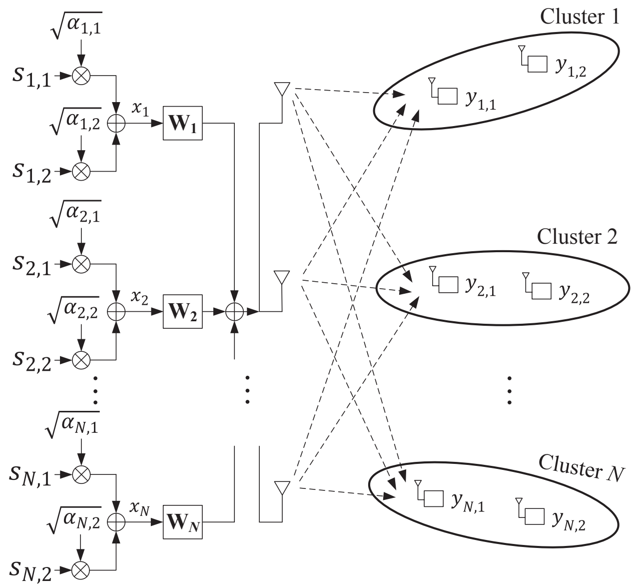

Fig. 1. The proposed downlink precoding NOMA system.

The base station superposes the signals of the two users in the power domain. In the k-th cluster, the signal of the strong user $s_{k,1}$ and that of the weak user $s_{k,2}$ are superposed as

$$x_k = \sqrt{\alpha_{k,1} P_k} s_{k,1} + \sqrt{\alpha_{k,2} P_k} s_{k,2}, \tag{1}$$

where $\mathbb{E}\left\{|s_{k,i}|^2\right\} = 1$ for $i = 1,\, 2$, P_k is transmission power, $\alpha_{k,1}$ and $\alpha_{k,2}$ denotes power allocation factors for the strong user and the weak user, respectively, and $\alpha_{k,1} + \alpha_{k,2} = 1$. In the n-th cluster, the received signals of the strong user and the weak user are defined as $y_{n,1}$ and $y_{n,2}$, respectively, given by

$$y_{n,i} = \mathbf{h}_{n,i} \sum_{k=1}^{N} \mathbf{w}_k x_k + n_{n,i} \quad \text{for} \quad i = 1,\, 2;\; n = 1, \cdots, N, \tag{2}$$

where $\mathbf{w}_k$ is the $N \times 1$ precoding vectors for the k-th cluster, $n_{n,1}$ and $n_{n,2}$ are additive white complex Gaussian noises with zero mean and variances σ_n^2, and $\mathbf{h}_{n,i}$ is the $1 \times N$ channel vector between user i and the base station. We assume that the transmitter knows full channel state information, and the channel is assumed to be Rayleigh fading with zero mean.

Block Diagonalization (BD) is used for the precoding scheme [8], which makes the value of $\mathbf{h}_m \mathbf{w}_n$ be 0 for $m \neq n$, and 1 for $m = n$. In the proposed NOMA system, the channel of the strong users in individual clusters are used to form the precoding vectors [3]. Let the channel matrix $\mathbf{H}$ be consisting of the channels of the strong users as

$$\mathbf{H} = [\mathbf{h}_{1,1}^T \cdots \mathbf{h}_{N,1}^T]^T. \tag{3}$$

The precoding matrix $\mathbf{W}$ is then given by

$$\mathbf{W} = [\mathbf{w}_1 \cdots \mathbf{w}_N] = \mathbf{H}^H (\mathbf{H}\mathbf{H}^H)^{-1} \mathbf{\Lambda}, \tag{4}$$

where $\mathbf{\Lambda}$ is a diagonal matrix to normalize the power of individual columns, and $\mathbf{w}_n$ is the precoding vector for the n-th cluster.

For the strong user in a specific cluster, the intra-cluster interference from the weak user can be removed by using perfect SIC. Also, the inter-cluster interference does not affect the strong user due to the use of BD precoding. Therefore, the signal $y_{n,1}$ of the strong user in the n-th cluster after SIC can be represented as

$$y_{n,1} = \mathbf{h}_{n,1} \mathbf{w}_n \sqrt{\alpha_{n,1} P_n} s_{n,1} + n_{n,1}. \tag{5}$$

The achievable rate $R_{n,1}$ can be represented by

$$R_{n,1} = \log_2 \left(1 + \frac{|\mathbf{h}_{n,1} \mathbf{w}_n|^2 \alpha_{n,1} P_n}{\sigma_n^2} \right). \tag{6}$$

For the weak user, the received signal can be written as

$$\begin{aligned} y_{n,2} = & \underbrace{\mathbf{h}_{n,2} \mathbf{w}_n \sqrt{\alpha_{n,1} P_n} s_{n,1}}_{\text{intra-cluster interference}} + \underbrace{\mathbf{h}_{n,2} \mathbf{w}_n \sqrt{\alpha_{n,2} P_n} s_{n,2}}_{\text{desired signal}} \\ & + \underbrace{\mathbf{h}_{n,2} \sum_{k=1, k \neq n}^{N} \mathbf{w}_k x_k}_{\text{inter-cluster interference}} + n_{n,2}. \end{aligned} \tag{7}$$

The achievable rate of the weak user is given by

$$R_{n,2} = \log_2 \left(1 + SINR_{n,2} \right), \tag{8}$$

where $SINR_{n,2}$ is defined as follows:

$$\frac{|\mathbf{h}_{n,2} \mathbf{w}_n|^2 (1 - \alpha_n) P_n}{|\mathbf{h}_{n,2} \mathbf{w}_n|^2 \alpha_n P_n + \sum_{k=1, k \neq n}^{N} |\mathbf{h}_{n,2} \mathbf{w}_k|^2 P_k + \sigma_n^2}. \tag{9}$$

Let us describe the goals of this study as follows: First, we propose a user clustering algorithm which select the strong and the weak user separately. Then, we introduce a optimal power allocation algorithm for maximizing the sum rate; while it still retains the QoS of the weak user by keeping the achievable rate of the weak user equal to or greater than a given target rate. The problem is formulated as

$$\begin{aligned} & \max_{\alpha_{n,1}, \alpha_{n,2}} (R_{n,1} + R_{n,2}) \\ & \text{subject to } R_{n,1}, R_{n,2} \geq R_t,\; \alpha_{n,1} + \alpha_{n,2} = 1. \end{aligned} \tag{10}$$

where $\alpha_{n,1}$ and $\alpha_{n,2}$ denote the allocated power ratio for the strong user and the weak user in the n-th cluster, respectively, and R_t is a given target rate. Second, we provide a reasonable value of R_t according to various settings of user number, cluster number and SNR value such that the weak user can always achieve this target rate. Please note that if R_t is not properly determined, the weak user may have little chance to achieve this target rate and thus only the strong user attains the QoS requirement. As a result, it returns to conventional multiuser MIMO case instead of NOMA. To make thing worse, the weak user can fail to meet the QoS requirement even if all the power has been allocated to him/her.

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