User Grouping for Non-orthogonal Multiple Access (NOMA)

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Abstract

An unprecedented growth is being witnessed in the number of connected devices in the current cellular networks due to the proliferation of smart devices and novel applications. Thus, new paradigms are being investigated to enhance the spectral efficiency and number of connections to support this deluge of traffic produced by these devices and applications. Non-orthogonal multiple access (NOMA) is a novel scheme that is envisioned to overcome the challenges of spectral efficiency and limited number of connections in the existing cellular networks compared to the traditional orthogonal frequency division multiplexing (OFDMA) scheme. In NOMA, multiple users can be scheduled non-orthogonally to enhance the spectral efficiency. However, a significant challenge is to find a set of users that can be scheduled or grouped together over the limited spectrum in efficient way. In this paper, we present a novel scheme based on matching games that can group multiple users on a spectrum resource to form a group such that the network wide utility is maximized. Simulation results reveal the effectiveness of our proposal in terms of spectral efficiency and number of connected devices.

Index Terms

Non-orthogonal multiple access, user-grouping, user-clustering, resource allocation, 5G

I. Introduction

Massive connectivity and high spectral efficiency are two key factors to bring 5G networks into fruition. These challenging factors are of keen interest for the network operators and are being investigated in order to support the tsunami of traffic produced in the existing networks [1]. A number of novel paradigms have been of keen interest such as dense deployment of small cells [2], caching at the edge networks [3]–[5], coexistence of licensed and unlicensed access [6], wireless network virtualization [7], [8] and etc. Indeed, significant performance gains in terms of spectral efficiency have been achieved by enabling these paradigms in the current networks. However, for massive connectivity, we need novel schemes that can further enhance the performance. Moreover, the biggest disadvantage of current orthogonal multiple access (OMA) schemes (i.e., the OFDMA scheme) is the number of served users, which will be limited by the number of spectrum resources (i.e., subchannels, resource blocks). Non-orthogonal multiple access (NOMA) has been considered as a key enabling technique for 5G cellular systems [9], which can alleviate the aforementioned challenge of OMA schemes and boost the performance in terms of spectral efficiency and massive connectivity. In NOMA, by exploiting the channel gain differences, multiple users are multiplexed into the transmission power domain and then non-orthogonally scheduled for transmission over the same spectrum resources. Thus, our aim is to group users based on channel conditions such that the network wide utility is maximized.

The paper is organized as follows. Section II discusses the system model and problem formulation. Section III explains the working of the proposed user grouping solution based on well-known matching theory. Section IV shows the simulation results. Finally, conclusion are drawn in Section V.

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II. System Model

We consider the downlink setting with one macro base station (MBS) that serves a set of cellular users (CUs) denoted by $\mathcal{M}$ and the number of CUs is M. Moreover, the MBS has a system bandwidth that is divided into a set of subchannels denoted $\mathcal{S}$, each of bandwidth B. In our model, multiple CUs who are scheduled over non-orthogonal subchannel form a group. Each NOMA group operates on a subchannel which is orthogonal to other subchannels allocated to other groups. Furthermore, the number of CUs per NOMA subchannel can range between 1 and $|\mathcal{M}|$. Let $\mathcal{M}_k$ be the set of active CUs grouped into the k-th subchannel. The power allocated to CU $m \in \mathcal{M}$ is denoted by P_m. Note that, we assume equal power on each CU in this work. then, let x_m be the transmitted symbol of CU m. The signal that CU m received from MBS in the k-th subchannel is then given by

$$y_m^k = h_m \sqrt{P_m} x_m^k + \sum_{m' \neq m | m' \in \mathcal{M}_k} h_m \sqrt{P_{m'}} x_{m'}^k \quad (1)$$

where z_m is the additive white Gaussian noise.

Note that all CUs scheduled on the same subchannel experiences interference by all other CUs of that subchannel. To demodulate the target message, each CU performs successive interference cancellation (SIC) after receiving the superposed signals [9]. The optimal order of SIC decoding is in the order of the increasing channel gains normalized by the noise. Specifically, the receiver of CU $m \in \mathcal{M}_k$ can cancel the interference from any other CU $m' \in \mathcal{M}_k$ with channel gain $|h_{m'}|^2/z_{m'} < |h_m|^2/z_m$, i.e., CU m first decodes the signal from UE m' then subtracts it and decodes its target signal x_m^k correctly from the received signal y_m^k in k-th subchannel. Then, the CU grouping variable β_m^k can be given as follows:

$$\beta_m^k = \begin{cases} 1 & \text{if CU } m \text{ is grouped into subchannel } k \\ 0 & \text{otherwise,} \end{cases}$$

Similarly, the achievable throughput for CU m in k-th subchannel can be expressed as:

$$R_{m,CU}^k = \log_2\left(1 + \frac{P_m|h_m|^2}{I_m^k + z_m}\right), \qquad (2)$$

where I_m^k is the interference that CU $m \in \mathcal{M}$ experiences due to the other CUs in k-th subchannel

$$I_m^k = \sum\nolimits_{m' \in \mathcal{M} | \frac{|h_{m'}|^2}{z_{m'}} > \frac{|h_m|^2}{z_m}} \beta_{m'}^k P_{m'} |h_m|^2. \qquad (3)$$

Next, our goal is to formulate a problem that maximizes the network utility which is captured by network sum-rate. Thus, we aim to group CUs as follows:

$$\begin{aligned} &\max_{\beta \in \{0,1\}} \sum_{k \in \mathcal{S}} \left(\sum_{m \in \mathcal{M}} \beta_m^k R_{m,CU}^k \right) \\ &\text{s.t.:} \\ &C_1 : 1 \leq \sum\nolimits_{m \in \mathcal{M}} \beta_m^k \leq |\mathcal{M}|, \ \forall k \in \mathcal{S}, \\ &C_2 : \sum\nolimits_{k \in \mathcal{S}} \beta_m^k = 1, \ \forall m \in \mathcal{M}. \end{aligned} \qquad (4)$$

Constraint C_1 states that a subchannel can schedule upto $\mathcal{M}$ CUs, however, the number of CUs per NOMA subchannel are generally set to two in order to reduce the hardware complexity for SIC whereas constraint C_2 ensures that each CU can be scheduled over one subchannel only. The formulated CU grouping problem in (4) is a combinatorial problem, and finding the solution becomes NP-hard, for a large set of CUs and subchannels in a practical amount of time [2]. Therefore, we use matching theory to map the problem (4) into a one-to-many matching game which has the ability to solve combinatorial problems. Moreover, we present a distributed matching game in which the CUs and subchannels act as players and we aim to find the set of CUs that can be grouped into the same subchannels.

III. Matching Game for User Grouping

In matching games, we need to define the preferences of both sides of players, i.e., CUs and subchannels. For CUs, the preference ranks all subchannel in a descending order in terms of achievable rate as follows:

$$U_m(k) = R_{m,CU}^k, \quad \forall k \in \mathcal{S}. \qquad (5)$$

Similarly, the subchannel finds a set $\mathcal{A}$ of two CUs that maximize the rate over its subchannel.

$$U_k(\mathcal{A}) = \sum\nolimits_{m \in \mathcal{A}} R_{m,CU}^k, \quad \forall \mathcal{A}, \qquad (6)$$

Note that finding the best set $\mathcal{A}$ of CUs with significant different channel gains by each subchannel is not trivial because in NOMA, CUs with significantly different channel gains over a subchannel are grouped together for best performance in terms of rate. Thus, we apply a hueristic approach in which we classify CUs based on their channel gains to reduce the number of combinations in finding the best $\mathcal{A}$. Next, we present our novel algorithm for CU grouping. Initially, the MBS collects the channel state information and sorts CUs in a decreasing order based on channel gains. Then, we divide the CUs into two classes based on pre-defined threshold (i.e., CUs greater than a certain threshold fall into the same class) which are denoted by Class A, and Class B as follows:

Sort users: $|h_1|^2 \geq |h_2|^2 \cdots \geq |h_i|^2 \geq \theta_A > |h_{i+1}|^2 \geq |h_{i+2}|^2 \geq \cdots |h_{|\mathcal{M}|}|^2 \geq \theta_B$.

Here, θ_A and θ_B represents the predefined threshold for a class. Moreover, the similarity between CUs in a class is based on a measure of the channel gains between them and the MBS. Note that, through such classification, we can determine the set of strong, and weak CUs in the network easily. Our goal is to select two CUs to form a group that can be scheduled into a subchannel. Once preference profiles are build by both sides, all CUs propose to their best subchannel based on their achievable rate. The MBS, on receiving all proposals from the CUs selects the two best CUs from each class over the subchannel. Moreover, the CUs which are not accepted by the subchannel, then propose again to the next best subchannel. Through this process, the MBS, once again selects the best CUs from each class over the subchannels. Note that a CU that is rejected by a subchannel cannot propose to the same subchannel again. Once all CUs have either been accepted to form a group over a subchannel or all the available subchannels have rejected the CUs and their is no subchannel to propose, then, the algorithm converges. Through this process, the proposed algorithm converges after limited number of iterations as the CUs and subchannels are limited in any network. The output of the algorithm would be the vector β representing the grouping variable.

IV. Simulation Results

We consider a downlink system in which the BS is assumed to be deployed at a fixed location, and we randomly deploy M cellular users following a homogeneous Poisson point process (PPP). We assume the system bandwidth to be 3 MHz. Note that the methodologies developed in this work can also be applied to any value of system bandwidth. Moreover, the wireless parameters are chosen according to the system model guidelines in [7]. Moreover, we compare the performance of our proposed scheme with the traditional OFDMA scheme. In the OFDMA scheme, CUs are assigned with an orthogonal number of RBs, i.e., no interference between the CUs. Note that, all statistical results are averaged over 500 runs of random locations of CUs, and RB gains.

In Fig. 1, we illustrate the total network sum rate (throughput) vs. the number of users under two schemes, NOMA and OFDMA. It can be seen that the total throughput of NOMA increase when the number of users increases until it becomes saturated, i.e., when the number of CUs increases significantly. Moreover, when the number of user is larger than 15, the total throughput continues to increase due to the multiuser diversity gain, but grows at a slower speed. Moreover, we can see that the performance of proposed scheme outperforms the traditional OFDMA scheme significantly. This signifies the importance of NOMA in bringing 5G networks into fruition.

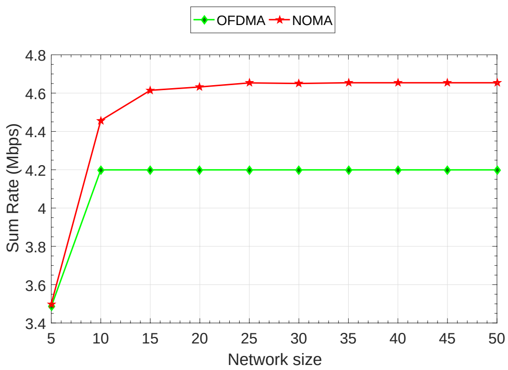

Fig. 1. Average sum-rate of NOMA and OFDMA schemes.

In Fig. 2, we compare the number of admitted users or number of connected CUs in the system for the proposed NOMA and OFDMA schemes. It can be seen that only 15 users (i.e., 3 Mhz bandwidth) can be admitted using the OFDMA scheme, whereas in the NOMA the number of admitted users are significantly higher, i.e., double of the OFDMA scheme. Thus, we can infer that NOMA will play a crucial role in enhancing the connectivity for the 5G networks.

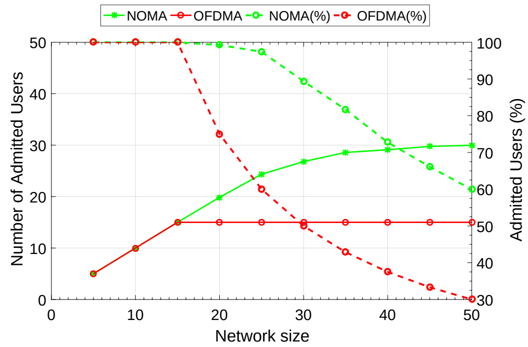

Fig. 2. Average admitted users vs. network size.

V. Conclusions

This paper studies the problem of user grouping over subchannels for non-orthogonal multiple access (NOMA) systems. We formulated the user grouping problem by scheduling users that can maximize the total sum-rate of network. Moreover, the presented solution can be implemented is decentralized manner. Simulation results reveal that our proposal significantly enhances the spectral efficiency and number of accessed devices compared to the traditional OFDMA based systems.

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