User Clustering by Matching Theory in Non-orthogonal Multiple Access

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Abstract

In this paper, we study the problem of user clustering in non-orthogonal multiple access (NOMA). Since the spectrum resource is limited, the NOMA can provide efficient resource utilization and massive connectivity in dense network setting. However, the main challenge of NOMA technique is how to group users into each cluster such that all users in the same cluster can share all the resource allocated to that cluster. We propose an optimization problem of the user clustering to maximize the total sum-rate of the network. To effective solve the formulated combinatorial problem we proposed a one-to-many matching game based on the well-known Gale-Shapely algorithm. Through simulation results, we show that the algorithm converges to an optimal solution in a limited iterations.

I. Introduction

In the forthcoming 5G network, the increase in mobile device requires larger bandwidth and higher data rate to fulfill the network performance and users quality of service. However, the spectrum resource is limited, therefore, a large number of devices will be dropped from the serving of network, and reduce the network performance. In NOMA, by exploiting the channel gain differences, multiple users are multiplexed into transmission power domain and then non-orthogonally scheduled for transmission on the same spectrum resources [1]. NOMA can provide efficient resource utilization and massive connectivity in dense network setting. Many recent works forcus on the resource allocation in NOMA [1]-[3]. In [2], the authors provide a heuristic user clustering algorithm based on a classification of users, i.e., strong and weak users on their channel conditions.

In this paper, we consider the problem of user clustering in LTE network with non-orthogonal multiple access (NOMA). We formulate a user clustering problem in which the users will be grouped into a number of groups with a given number of LTE resource blocks. The proposed algorithm is based on the matching theory approach and it can converge within a limited iteration.

II. System model

We consider the downlink of a single cell consisting single macro base station (BS) serving a set of subscribed users $\mathcal{U}$. The system bandwidth $\mathcal{C}$ which is divided into frequency resource blocks (RBs), each of bandwidth B. That is, the total number of RBs are given as $\Omega = \mathcal{C} / B$.

Users who are non-orthogonally scheduled over the same set of RBs form a NOMA cluster.

However, each NOMA cluster operates on a set of RBs which is orthogonal to other sets of RBs belong to other clusters.

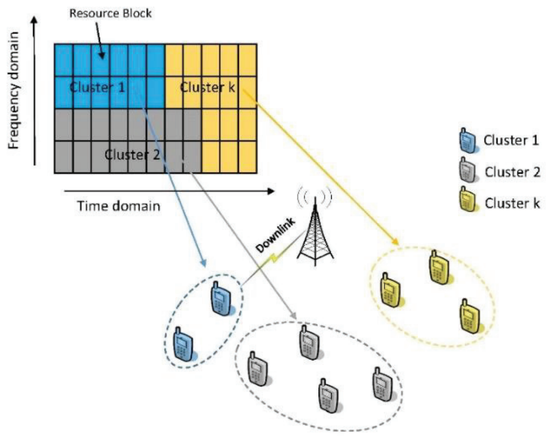

Figure 1: System model

The number of users per NOMA cluster ranges between 2 and $|\mathcal{U}|$. Also, the number of RBs allocated per cluster is represented by δ^k where $1 \le \delta^k \le \Omega$. Let $\mathcal{S}$ be the set of clusters and $\mathcal{S}_k$ be the set of active users grouped into cluster k th. The receiver of UE $j \in \mathcal{S}$ can cancell the interference from any other UE $i \in \mathcal{S}$ with channel gain $|h_i|^2/z_i < |h_j|^2/z_j$. We now define a user clustering (grouping) variable $\beta_j^k = 1$ if UE is j grouped into cluster k, and 0 otherwise. The achievable throughput for UE j in downlink NOMA cluster k th can be expressed as

$$R_j^k = \delta^k B \log_2\left(1 + \frac{P_j |h_j|^2}{I_j^k + \delta^k B z_j}\right), \qquad (1)$$

where I_j^k is the interference that UE $j \in \mathcal{U}$ receives from other UEs in cluster k th.

$$I_j^k = \sum\nolimits_{i \in \left\{\mathcal{S}_k \mid \frac{|h_i|^2}{z_i} > \frac{|h_j|^2}{z_j}\right\}} \beta_i^k P_i |h_j|^2 . \qquad (2)$$

III. Problem Formulation and Solution

The problem of user clustering can be formulated as follows

$$\begin{aligned} &\mathbf{UC}: \max_{\boldsymbol{\beta}} \sum_{j \in \mathcal{U}} \omega_j \sum_{k \in \mathcal{S}} \beta_j^k R_j^k \\ &\text{s.t.: } C_1 : \sum_{j \in \mathcal{U}} \sum_{k \in \mathcal{S}} \beta_j^k P_j \le P_T, \\ &C_2 : \sum_{k \in \mathcal{S}} \beta_j^k = 1, \forall j \in \mathcal{U}, \qquad (3) \\ &C_3 : 2 \le \sum_{j \in \mathcal{U}} \beta_j^k \le |\mathcal{U}|, \forall k \in \mathcal{S}, \\ &C_4 : \beta_j^k \in \{0,1\}, \forall k, j. \end{aligned}$$

Where C_1 denotes the total power constraint. The user clustering constraint C_2, C_3 ensure that one user can be assigned to at most one cluster, while at least two users are grouped into each downlink NOMA cluster. The problem in (3) is the combinatorial problem which requires exponential efforts through exhaustive search. In the dense setting it is impractical to implement the centralized exhaustive search; therefore, it motivates us to apply matching theory to effective solve this combinatorial problem.

In user clustering the two set of players are the clusters (MBS) and the users, both of the set of players make a preference profile to evaluate each other. The preference profile in our case is the rate function and given by the following equation:

$$U_k(j) = R_j^k . \qquad (4)$$

Where $U_k(j)$ is the preference function of each cluster to rank each user j. The user clustering problem (3) can be formulated as a one-to-many matching game in which one cluster can match with many users while one user can only match with one cluster.

The matching game starts by each user proposes to the most preferre cluster who provide it highest achivable rate. The cluster will collect all the achivable rate information of all users along with the proposal and rank each user according to maximum rate. The second consideration is each cluster needs to make the quota information before allowing a user to admit to that cluster. In sumary, users will propose and cluster will accept the proposal. Our user clustering problem which is a one-to-many matching problem can be solved by applying the well-known Gale-Shapely algorithm [4]. The output would be the matrix which is the variable of the formulated optimization problem (3).

IV. Numerical Results.

The network scenario in our numerical simulation is shown in Fig. 2, where users are randomly deployed inside a macro cell of radius 500m which belong to the InP. We assume number of available LTE resource blocks is 100 each of which has a total bandwidth of 180 KHz. We set the $P = 40W$. The noise power is assumed to be 10^{-13}W for all subchannel. Channel gains are set as $g_{n,j} = \chi\, d_{n,j}^{-\beta}$, where χ is a random value generated according to the Rayleigh distribution, $d_{n,j}$ is the geographical distance between BS n and user j of $\beta = 3$ is the pathloss exponent.

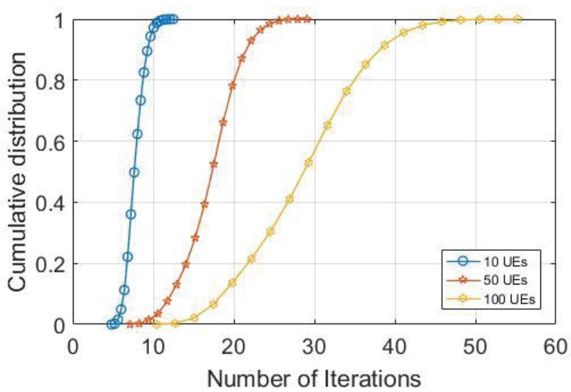

Figure 2: Cumulative distribution of Number of Iteration in three instances of number of users.

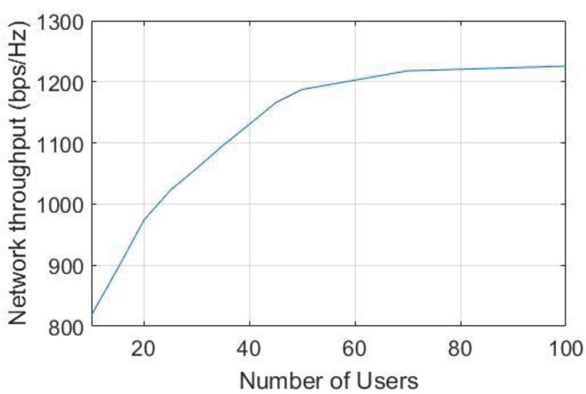

Figure 3: Network throughput vs number of users.

In Fig. 2 it can be seen that our proposed matching game converges to stable solution with limited number of iteration. Moreover, the number of iteration of proposed matching game increase with the increase of number of users. In Fig. 3, it is observed that the network throughput increase with the increase of number of users; however, the network throughput saturates when the number of users is sufficient large, i.e., larger than 70 users.

V. Conclusions

We have developed a matching based approach to effective solve the problem of user clustering in non-orthogonal multiple access. Numerical results show that our proposed algorithm converges quickly to an optimal solution with limited number of iteration in all simulation setting.

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