User Association Coalition Games with Zero-Forcing Beamforming and NOMA

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***Abstract*—In future fifth generation (5G) and beyond wireless technologies, ultra-dense networks (UDNs) will be employed to serve a massive amount of devices with mobile access. One of the major challenges in UDNs is user association, which is essential for dealing with intra- and inter-cell interference. In this paper, a user association problem is formulated and solved via a game theoretical approach. Specifically, in an effort to mitigate interference and maximize the sum-rate of the system, a coalition game is employed which exploits the cooperation among the small base stations (SBSs). Two algorithms are proposed, one where zero-forcing (ZF) or regularized ZF (RZF) beamforming is applied and another where ZF and non-orthogonal multiple access (NOMA) are jointly considered. Simulation results show that the proposed algorithms can significantly improve the overall sum-rate, providing near-optimal solutions while keeping the complexity low.**

***Index Terms*—Coalition games, user association, zero-forcing beamforming, non-orthogonal multiple access.**

I. Introduction

The constantly increasing number of devices with mobile access, emerging with the development of Internet of Things (IoT), has caused mobile data traffic to grow 18-fold over the past 5 years [1]. To deal with the unprecedented volume of mobile data traffic, 5G and beyond networks must boost their overall throughput. The Cloud-Radio Access Network (C-RAN) is a promising network architecture which can provide coordination among heterogeneous networks (HetNets) and handle resource allocation efficiently [2]. C-RANs are often considered for ultra-dense networks (UDNs), which is an emerging key technology for future generation wireless network architectures [3]. Nevertheless, UDNs still face many challenges to surpass, due to the deployment of multiple small base stations (SBSs) which can cause severe interference. In C-RAN the information from all SBSs can be processed at a centralized base band unit (BBU) pool, which establishes dynamic and flexible resource allocation.

User association is a pivotal mechanism that can, among other things, minimize interference, especially in ultra-dense millimeter wave (mmWave) HetNets where interference can be critical. Many schemes have been considered to solve user association problem. The authors in [4] consider the optimization problem of user association as a Nash bargaining problem in the context of HetNets, and show that when coalition is adopted the sum-rate is effectively maximized. In [5], a greedy user selection algorithm is proposed in a multi-user downlink network with zero-forcing (ZF) beamforming which performs closely to an exhaustive search scheme. Recent work has shown that game theoretical approaches have been proven to be very efficient in multi-player scenarios [6]. In particular, coalition games are capable of providing low-complexity optimal and sub-optimal solutions to resource allocation problems [7], [8]. In [7], a coalition game algorithm is proposed for non-orthogonal multiple access (NOMA) networks. The optimum weight values for each NOMA pair are evaluated, providing fairness between the strong and the weak user. A coalition game was also designed in [8], aiming to efficiently deploy coordinated multi-point transmissions through cooperation among the network's remote radio heads.

Motivated by the above, in this paper, we consider a user association problem in a cellular downlink network with ZF, but in contrast to [5], we solve it as a coalition game. Specifically, we propose an algorithm where both ZF and regularized ZF (RZF) are applied at the small base stations (SBSs), utilizing the ability of these techniques to eliminate intra-cell interference. We show that our algorithm significantly outperforms the conventional minimum-distance association scheme in terms of the network's sum-rate. Furthermore, similar to [7], we exploit the benefits of NOMA, in order to increase the number of users being served. A second algorithm is investigated, which implements a coalition game that jointly takes into account ZF and NOMA to associate the users with the SBSs. It is shown that this combination (ZF with NOMA), provides substantial gains to the sum-rate performance. To the best of our knowledge, these two techniques have never been jointly investigated before in this context. The proposed algorithms utilising cooperation via coalition games are of great importance for future networks, as they are of low-complexity and can achieve near-optimal solutions.

II. System Model

We consider a downlink cellular network and focus on a circular area with radius R_D, in which M SBSs and K users are randomly located, with $K \geq M$. We denote by $\mathcal{M} = \{1, 2, \ldots, M\}$ and $\mathcal{K} = \{1, 2, \ldots, K\}$, the sets of the SBSs and the users, respectively. Each SBS transmits with power P_t and is equipped with N antennas that can support up to N_{RF} users, where N_{RF} is the number of available radio frequency (RF) chains. Each SBS applies either the ZF or the RZF beamforming technique and utilises the NOMA scheme in the form of pairs. The described system model is shown in Fig. 1. All signals from the SBSs to the users are processed through a BBU pool of a C-RAN architecture.

A. Channel Model

The set of users associated with the j-th SBS is indicated with $\mathcal{K}_j$ and the cardinality of the set is denoted by K_j, where

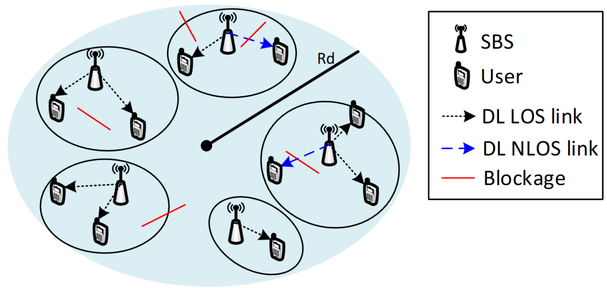

Fig. 1. . The network model with $K = 10$ users associated with $M = 5$ SBS. The solid red lines represent the blockages which indicate if the received signal at the user is LOS (dotted black lines) or NLOS (dashed blue lines).

$K_j \leq N_{\mathrm{RF}}$ and $\sum_{j=1}^{M} K_j = K$. The channel matrix of a SBS $j \in \mathcal{M}$ serving K_j users is $\mathbf{H}_j = [\mathbf{h}_{1,j}^*, \mathbf{h}_{2,j}^*, \ldots, \mathbf{h}_{K_j,j}^*] \in \mathbb{C}^{K_j \times N}$, where $\mathbf{h}_{k,j}^* \in \mathbb{C}^{1\times N}$ is the channel vector of user $k \in \mathcal{K}_j$ associated with SBS j. All channel coefficients are modeled as block Rayleigh fading with unit variance, i.e. $\mathbf{h}_{k,j} \sim \mathcal{CN}(0, \mathbf{I})$, and the SBS are assumed to have full channel state information (CSI). The path-loss model is considered to be $d_{k,j}^{-\alpha}$ where $d_{k,j}$ is the distance between user k and SBS j with $\alpha \geq 2$ being the path-loss exponent. We consider both line-of-sight (LOS) and non-LOS (NLOS) cases for which different values of α are assigned. The probability of a LOS link is $P[\mathrm{LOS}] = \exp(-\beta d)$, where β is a non-negative constant, and $1-P[\mathrm{LOS}]$ is the probability of NLOS. The constant β, characterizes the density and length of the blockages [10], presented in Fig. 1. All links contain additive white Gaussian noise with variance σ^2.

B. Precoding Schemes

1) ZF and RZF: The ZF precoding technique applied at the j-th SBS uses the pseudoinverse of $\mathbf{H}_j$, denoted as $\mathbf{H}_j^\dagger = \mathbf{H}_j^*(\mathbf{H}_j\mathbf{H}_j^*)^{-1}$. In similar fashion, $\mathbf{H}_j^\dagger = \mathbf{H}_j^*(\mathbf{H}_j\mathbf{H}_j^* + \frac{\sigma^2}{P_t}\mathbf{I})^{-1}$ is applied for the RZF case, where $\mathbf{I}$ is the $K_j \times K_j$ identity matrix. For both schemes, the vectors are then normalized producing weight vectors $\mathbf{w}_k$, corresponding to the k-th user, which are applied for removing intra-cell interference [5]. Then, the signal-to-interference-plus-noise ratio (SINR) at the k-th user associated with the m-th SBS is

$$\mathrm{SINR}_{k,m} = \frac{|\mathbf{h}_{k,m}\mathbf{w}_k|^2 d_{k,m}^{-\alpha}}{I_{k,m} + \frac{\sigma^2}{P_t}}, \tag{1}$$

where the value $\mathbf{h}_{k,m}\mathbf{w}_k$ is the channel coefficient after ZF or RZF precoding. The interference $I_{k,m}$ in (1) is

$$I_{k,m} = \mathbb{1}_{\mathrm{RZF}} \sum_{\substack{i=1\\ i\neq k}}^{K_m} |\mathbf{h}_{i,m}\mathbf{w}_i|^2 d_{k,m}^{-\alpha} + \sum_{\substack{j=1\\ j\neq m}}^{M} \sum_{i=1}^{K_j} |\mathbf{h}_{i,j}\mathbf{w}_i|^2 d_{k,j}^{-\alpha}, \tag{2}$$

where $\mathbb{1}_{\mathrm{RZF}} = 1$ if RZF is employed and $\mathbb{1}_{\mathrm{RZF}} = 0$ otherwise, since only ZF achieves intra-cell interference elimination by ensuring orthogonality among the users of the SBS.

2) ZF+NOMA: In this case, we consider K' additional users which are no longer served with the ZF scheme. NOMA is a multiple access scheme which allows the additional K' users to be served by pairing them with the rest of the users K [7]. Each pair requires one strong and one weak user utilizing the same resources apart from the power, which is separated among the users of the pair [9], i.e. the weak user requires more power since its channel conditions are poorer. In this case, the strong user cancels the interference occurred by the weak user's signal, using successive interference cancellation (SIC) techniques [7], while the weak user treats the strong user's signal as interference. We denote by p_w and p_s the power allocation coefficients of the weak and strong user, respectively, with $p_w > p_s$ and $p_w + p_s = 1$. In this case, the SINR of the strong user k, and of the weak user k' is

$$\mathrm{SINR}_{k,m} = \frac{p_s|\mathbf{h}_{k,m}\mathbf{w}_k|^2 d_{k,m}^{-\alpha}}{I_{k,m} + \frac{\sigma^2}{P_t}}, \tag{3}$$

and

$$\mathrm{SINR}_{k',m} = \frac{p_w|\mathbf{g}_{k',m}\mathbf{w}_k|^2 d_{k',m}^{-\alpha}}{I_{k',m} + \frac{\sigma^2}{P_t}}, \tag{4}$$

where $\mathbf{g}_{k',j}^* \in \mathbb{C}^{1\times N}$ is the channel vector of user $k' \in \mathcal{K}_j'$. $\mathcal{K}_j'$ is the set of the weak users associated with SBS j and the cardinality of the set is denoted by K_j'. $I_{k,m}$ and $I_{k',m}$ represent the interference affecting the signals of the strong user k and the weak user k', respectively, and are

$$I_{k,m} = \sum_{\substack{j=1\\ j\neq m}}^{M} \sum_{i=1}^{K_j} p_s|\mathbf{h}_{i,j}\mathbf{w}_i|^2 d_{k,j}^{-\alpha} + \sum_{j=1}^{M} \sum_{\substack{i=1\\ i\neq k'}}^{K_j'} p_w|\mathbf{g}_{i,j}\mathbf{w}_i|^2 d_{k,j}^{-\alpha}, \tag{5}$$

and

$$I_{k',m} = \sum_{j=1}^{M} \sum_{i=1}^{K_j} p_s|\mathbf{h}_{i,j}\mathbf{w}_i|^2 d_{k',j}^{-\alpha} + \sum_{j=1}^{M} \sum_{\substack{i=1\\ i\neq k'}}^{K_j'} p_w|\mathbf{g}_{i,j}\mathbf{w}_i|^2 d_{k',j}^{-\alpha}, \tag{6}$$

where K_j' indicates the number of weak users served with NOMA by the j-th SBS, with $K_j' \leq K_j$. We assume that the users served using the ZF scheme are the strong users and that the SIC conditions hold, i.e. $\mathrm{SINR}_{k,m} \geq \mathrm{SINR}_{k',m}$.

C. Problem Formulation

In this paper, the user association problem is formulated, aiming to maximize the sum-rate of all the small cells of the network. The data rate of user k served by the m-th SBS is

$$R_{k,m} = B\log_2(1 + \mathrm{SINR}_{k,m}), \tag{7}$$

where B is the available bandwidth and SINR is calculated as above from (1), (3) or (4), depending on the case. With the applied ZF/RZF techniques, the SINR of each user can be increased. However, the association of each user is critical as it affects the inter-cell interference caused to the rest of the network's users. Therefore, the overall data rate is highly depended on the user selection. The user association problem based on the aforementioned utility is formulated as follows

$$\max_{\{\mathbf{x}_1,\mathbf{x}_2,\ldots,\mathbf{x}_M\}} \sum_{m=1}^{M} x_{k,m}R_{k,m}, \tag{8a}$$

$$\text{subject to } x_{k,m} \in \{0,1\}, \forall k \in \mathcal{K}, \forall m \in \mathcal{M}, \tag{8b}$$

$$\sum_{m=1}^{M} x_{k,m} = 1, \forall m \in \mathcal{M}, \tag{8c}$$

$$\sum_{i=1}^{K} x_{i,m} \leq N_{\mathrm{RF}}, \forall m \in \mathcal{M}, \tag{8d}$$

where $x_{k,m}$ is a binary value denoting whether or not the k-th user is associated with the m-th SBS and $\mathbf{x}_i = \{x_{k,i}\}$, $k \in \mathcal{K}$ is the set of cardinality K, defining each user's association with the i-th SBS. Constraint (8c) ensures that each user is associated with only one SBS. Constraint (8d) guarantees that the number of users associated with a SBS does not exceed the number of available RF chains N_{RF}.

The formulated problem is non-convex and difficult to transform to a convex problem [7]. Treating it as a coalition game, as shown in Section III, the problem can be solved.

III. Coalition Formation Based Algorithm

In this section, two algorithms based on coalition games are presented. The proposed algorithms provide a user association solution by exploiting the cooperation among the SBS, thus maximizing the total sum-rate. The formulated problem described in Section II-C, is defined as a coalition game $(\mathcal{K}, \mathcal{X}, \mathcal{R})$ with a non-transferable utility U [6], where $\mathcal{K}$ is the player set consisting of the users, set $\mathcal{X} = \{\mathbf{x}_1, \mathbf{x}_2, ..., \mathbf{x}_M\}$ is the set consisting of the vectors indicating the user-SBS associations and $\mathcal{R}$ is the achievable data rate of all the players for a given association $\mathcal{X}$.

A partition of the users, among the available SBSs, is denoted by $\mathcal{S} = \{S_1, S_2, ..., S_M\}$, where S_m is the coalition consisting of the users associated with the m-th SBS. For each coalition $S_m \in \mathcal{S}$, $m \in \mathcal{M}$, the conditions $S_m \cap S_l = \emptyset$, $\forall m \neq l$ and $\bigcup_{m=1}^{M} S_m = \mathcal{K}$ are satisfied. The utility function of a coalition m is

$$U(S_m) = \{\sum_{k=0}^{K_m} u_k | u_k = R_{k,m}, \forall k \in S_m\} \tag{9}$$

where u_k is the payoff value of each user which has been defined as the user's data rate. Before we present the proposed algorithms, the following three definitions are introduced.

Definition 1: (Preference) For any user $k \in \mathcal{K}$, we use the symbol $\succ_k$ to denote its preference between two coalitions S_m and $S_{m'}$, $m \neq m'$. The decision of a user k depends on whether or not the utility values of the two coalitions will increase.

$$S_{m'} \succ_k S_m \Leftrightarrow U(S_m \setminus \{k\}) + U(S_{m'} \cup \{k\}) > U(S_m) + U(S_{m'}). \tag{10}$$

Definition 2: (Split and merge operation) Given two different partitions $\mathcal{S}$ and $\mathcal{S}'$, where $\mathcal{S}'$ occurs from partition $\mathcal{S}$ if user k moves from coalition $S_m \in \mathcal{S}$ and joins $S_{m'} \in \mathcal{S}'$. User $k \in \mathcal{K}$, decides to leave its current coalition if and only if its preference condition (Definition 1) is satisfied. The split and merge operation can be written as

$$\{S_m, S_{m'}\} \rightarrow \{S_m \setminus \{k\}, S_{m'} \cup \{k\}\}. \tag{11}$$

Note that for the above operation, the user k joins the other partition if $|S_{m'}| < N_{\mathrm{RF}}$. Otherwise, a user k' in coalition $S_{m'}$ is selected at random and swapped with k based on the following definition.

Definition 3: (Swap operation) Two users are said to be swapped, if and only if, the preference condition (Definition 1) is satisfied for both of them. Then, the partitions are updated accordingly as

$$\{S_m, S_{m'}\} \rightarrow \{S_m \setminus \{k\} \cup \{k'\}, S_{m'} \setminus \{k'\} \cup \{k\}\}. \tag{12}$$

Algorithm 1 Coalition game algorithm with ZF/RZF

Initializing users with a random parition $\mathcal{S}_{ini}$
Denote current partition $\mathcal{S}_c \leftarrow \mathcal{S}_{ini}$
repeat
    Randomly select a user k of coalition $S_m \in \mathcal{S}_c$
    Randomly select a user k' of coalition $S_{m'} \in \mathcal{S}_c$
    if $|S_{m'}| = N_{\mathrm{RF}}$ **then**
        Assume $\mathcal{S}_{tmp} \leftarrow$ swap user k with user k'
        if $\mathcal{S}_{tmp} \succ_k \mathcal{S}_c$ **then**
            $\mathcal{S}_c \leftarrow \{\mathcal{S}_c \setminus \{S_m, S_{m'}\}\} \cup \{S_m \setminus \{k\} \cup \{k'\}, S_{m'} \setminus \{k'\} \cup \{k\}\}$
    else
        Assume $\mathcal{S}_{tmp} \leftarrow$ user k joins $S_{m'}$
        if $\mathcal{S}_{tmp} \succ_k \mathcal{S}_c$ **then**
            $\mathcal{S}_c \leftarrow \{\mathcal{S}_c \setminus \{S_m, S_{m'}\}\} \cup \{S_m \setminus \{k\}, S_{m'} \cup \{k\}\}$
until

A. Coalition game algorithm with ZF/RZF

The first algorithm is based on ZF/RZF. Initially all users are allocated randomly to the available SBSs. At each iteration, a user associated with SBS, say m, is randomly selected. By selecting a different SBS m', $m \neq m'$, thus selecting another coalition, we check if the above definitions are satisfied. In the case where this is true, (11) or (12) are applied accordingly. The pseudocode of the proposed algorithm is provided in Algorithm 1. In what follows, proof is provided that Algorithm 1 converges and that is D_p stable.

Convergence: Starting at any initial combination, the user association game of Algorithm 1 is guaranteed to converge at a final state.

Proof. In order to increase the game utility U, the users perform either the *split and merge* or the *swap* operation, thus constantly modifying the partition set. Consider two successive iterations i and $i+1$, and assume that partition $\mathcal{S}_{i+1}$ was formed from $\mathcal{S}_i$, after an operation is applied. Both operations, take place if and only if the game utility U is strictly increased. This can be written as

$$\mathcal{S}_i \rightarrow \mathcal{S}_{i+1} \Leftrightarrow U(\mathcal{S}_i) < U(\mathcal{S}_{i+1}). \tag{13}$$

Therefore, the game utility value is always increasing, that is,

$$\mathcal{S}_{ini} \rightarrow \mathcal{S}_1 \rightarrow \mathcal{S}_2 \rightarrow \cdots \rightarrow \mathcal{S}_{fin}, \tag{14}$$

where $\mathcal{S}_{ini}$ and $\mathcal{S}_{fin}$ is the initial and final partition set of the game, respectively. Hence, the sum-rate is guaranteed to improve at each new partition set. Sine the number of users is finite, the number of partition sets is also finite and is based on the Bell number [12]. Therefore, the sequence in (14) is guaranteed to converge to the final state $\mathcal{S}_{fin}$. □

D_p *stability*: The final partition set $\mathcal{S}_{fin}$ is D_p stable.

Proof. A partition $\mathcal{S}$ is D_p stable, if for any partition set $\mathcal{S}'$ that occurs from $\mathcal{S}$ when a user moves or a pair of users is swapped, $U(\mathcal{S}) \geq U(\mathcal{S}')$. Suppose the final partition $\mathcal{S}_{fin}$ of Algorithm 1 is not D_p stable. Then, there must exist a user $k \in \mathcal{K}$ that prefers to leave its current coalition and join another. This will form a new partition $\mathcal{S}_{tmp}$, where $\mathcal{S}_{tmp} \succ_k \mathcal{S}_{fin}$ which contradicts the fact that $\mathcal{S}_{fin}$ is the final partition. Therefore, the final partition of Algorithm 1 is D_p stable. □

Algorithm 2 Coalition game algorithm with ZF and NOMA

Algorithm 1 is executed
Randomly pair K' additional users with the K users of the first game, i.e. $\mathcal{S}_{ini}^{\text{NOMA}}$
Denote current partition $\mathcal{S}_c^{\text{NOMA}} \leftarrow \mathcal{S}_{ini}^{\text{NOMA}}$
repeat
  Select a NOMA user k of coaltion $S_m \in \mathcal{S}_c^{\text{NOMA}}$
  if $|S_{m'}| = N_{\text{RF}}$ **then**
    Select a user k' of coalition $S_{m'} \in \mathcal{S}_c^{\text{NOMA}}$
    $\mathcal{S}_{tmp}^{\text{NOMA}} \leftarrow$ swap case of NOMA users k and k'
    if $\mathcal{S}_{tmp}^{\text{NOMA}} \succ_k \mathcal{S}_c^{\text{NOMA}}$ **then**
      $\mathcal{S}_c^{\text{NOMA}} \leftarrow \{\mathcal{S}_c^{\text{NOMA}} \setminus S_m, S_{m'}\} \cup \{S_m \setminus \{k\} \cup \{k'\},\ S_{m'} \setminus \{k'\} \cup \{k\}\}$
  else
    $\mathcal{S}_{tmp}^{\text{NOMA}} \leftarrow$NOMA user k pairs with a user of $S_{m'}$
    if $\mathcal{S}_{tmp}^{\text{NOMA}} \succ_k \mathcal{S}_c$ **then**
      $\mathcal{S}_c^{\text{NOMA}} \leftarrow \{\mathcal{S}_c^{\text{NOMA}} \setminus S_m, S_{m'}\} \cup \{S_m \setminus \{k\}, S_{m'} \cup k\}$
until

Complexity: Each iteration executes K number of computational operations, to calculate the data rate of each user. Assuming Algorithm 1 is performed for C number of iterations, then the complexity of the algorithm is $\mathcal{O}(CK)$, which is much smaller compared to the complexity of the exhaustive search which is $\mathcal{O}(C^K)$.

B. Coalition game algorithm with ZF and NOMA

The second proposed algorithm considers NOMA as well, meaning that a dominant and a weak user are paired to increase the number of users served by the network simultaneously. Algorithm 2 first executes Algorithm 1 with ZF, associating K users with M SBSs as shown in Section III-A. Then K' additional users are considered and participate in another game. Algorithm 2 pairs the additional K' with the dominant K users, based on the NOMA scheme. Starting from a random pair allocation, with partition $\mathcal{S}_{ini}^{\text{NOMA}}$, the coalition game initiates a number of iterations with the K' users used as players. The algorithm in this case, selects a user $k \in K'$ and activates a split and merge or a swap to test a different pairing. Note that the SIC condition must be satisfied to ensure that the pair can apply NOMA. At each iteration the modified partition is compared and gets accepted only when the overall sum-rate is increased. Similar to the previous algorithm, complexity, convergence and stability are all satisfied, therefore a final partition will be reached within a limited number of iterations converging at a sub-optimal solution.

C. Coalition game using the Simulated Annealing algorithm

The Simulated Annealing algorithm (SAA) allows us to approximate the global optimum solution [7] for the formulated user association problem. This is achieved by sometimes allowing the algorithm to accept a new partition set $\mathcal{S}_{i+1}$, even when the utility value of the new partition, i.e. $U(\mathcal{S}_{i+1})$, is lower than the current one, that is, $U(\mathcal{S}_i) > U(\mathcal{S}_{i+1})$. In particular, if the utility value of the game is higher after a swap or a split and merge operation, then the new state is immediately accepted as described in (13). However, in order to avoid ending up at a local optimum, we use a probabilistic approach, by applying the Metropolis-Hastings algorithm

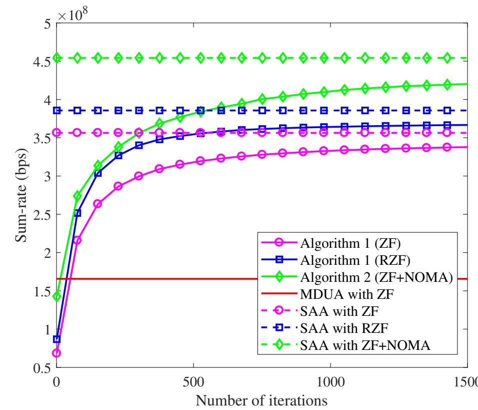

Fig. 2. Sum-rate versus the number of iterations.

[11], which allows us of accepting a worse user association. The probability of a partition $\mathcal{S}_{i+1}$ being accepted, when $U(\mathcal{S}_{i+1}) < U(\mathcal{S}_i)$, is decided by the following probability

$$P_{\text{SAA}} = \tau \exp\left(\frac{U(\mathcal{S}_{i+1}) - U(\mathcal{S}_{max})}{U(\mathcal{S}_{max})}\right), \tag{15}$$

where τ is the temperature of the SAA and S_{max} is the up to that point maximum sum-rate value. Using a large number of iterations ensures that the algorithm converges to a global optimum partition which is S_{max}.

IV. Numerical Results

In this section, numerical results are presented to demonstrate the performance gains from the proposed algorithms on the overall data rate. The following parameters were used: $M = 5$, $N = 6$, $N_{\text{RF}} = 6$, $K = 60$ and $\sigma^2 = -90$ dBm. The SBSs and the users were randomly distributed in a cell of radius $R_D = 50$ m. The system bandwidth is considered to be 20 MHz. The path-loss exponents are $\alpha = 2$ for the LOS case and $\alpha = 4$ for the NLOS. The power coefficients of each pair in the ZF+NOMA scheme are set to $p_w = 0.7$ and $p_s = 0.3$ for the weak and the strong user, respectively.

Fig. 2 shows the system sum-rate achieved by the proposed schemes over the number of iterations along with the minimum-distance based user association (MDUA). As it can be observed from the figure, since the users are initially associated randomly, the sum-rate of both algorithms at iteration 0 is lower than the MDUA scheme. However, it is shown that the proposed schemes outperform MDUA after just 50 iterations, indicating that a conventional scheme is not necessary for the initial association. In addition, both algorithms continue to increase the system's sum-rate as the iteration number increases reaching a final value which is significantly improved compared to the MDUA. It is shown that 1500 iterations are sufficient for the game to converge. Algorithm 2 can serve K' additional users, hence the data rate of those users contributes to the overall sum-rate, resulting in a higher value. The SAA algorithm is included with $\tau = 0.2$ to approximate the global optimum value. In contrast with the outstanding low number of iterations required by our proposed algorithms to converge, for the SAA scheme 10^5 iterations were used to ensure that the utility value $U(S_{max})$ approximates the global optimum accurately. Fig. 2 shows

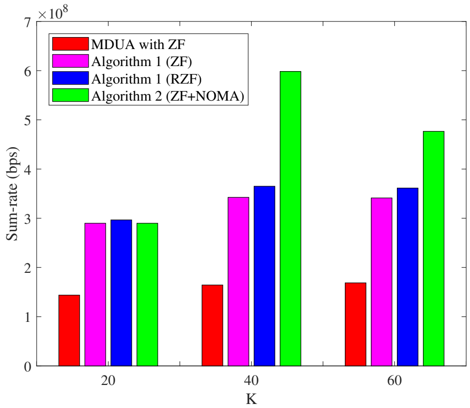

Fig. 3. Sum-rate at iteration 1500 versus the number of users.

that the final values $U(\mathcal{S}_{fin})$ achieved by Algorithm 1 and Algorithm 2, successfully provide a near-optimal solution.

Fig. 3 presents the converged sum-rate value achieved by the proposed schemes along with the MDUA scheme for three different number of users (20, 40 and 60). As we can see, the algorithms outperform the MDUA scheme, regardless of the number of users. The converged value of Algorithm 1 using RZF achieves slightly higher sum-rate compared to the same algorithm with ZF. The ZF+NOMA user association scheme produces significantly higher sum-rate than the rest of the schemes, with the exception of the case of 20 users, where NOMA is not applied as the total number of users can be served with ZF. In our simulations, $MN = 30$, hence for the case of 20 users all the users are served with ZF. This explains why ZF+NOMA has the same value as ZF with 20 users. In the case of 40 users, ZF+NOMA achieves a remarkably higher value than the rest of the schemes. However, in the case of 60 users, even though the ZF+NOMA scheme still outperforms the other schemes, it is lower compared to the performance with 40 users. This shows that the inter-cell interference caused by the additional K' users, in this case, begins to have an impact over the benefits provided by NOMA.

Focusing on Algorithm 2, three different cases of power allocation $\mathbf{p} = [p_w, p_s]$ are presented in Fig. 4, namely $[0.7, 0.3]$, $[0.5, 0.5]$ and $[0.9, 0.1]$. As it can be observed from the figure, the gains achieved with NOMA are subject to the power allocation. Specifically, while p_s increases, the achievable sum-rate is higher. However, p_w must be considerably higher than p_s to ensure sufficient data rate for the weak users. The case of Algorithm 1 with ZF is also included in Fig. 4. We observe that every ZF+NOMA case in Fig. 4 outperforms the ZF scheme, illustrating the performance improvement achieved with Algorithm 2, where the ZF precoding technique and the NOMA scheme are jointly considered.

V. Conclusion and Future Work

Although Cloud-RANs with dense deployment can be very effective for 5G and beyond networks, interference can significantly limit their potential gain. User association schemes can deal with challenges emerging from UDN deployment effectively. In this paper, a game-theoretic approach was applied ensuring the benefits of digital precoding techniques and NOMA, which are both susceptible to user association. The

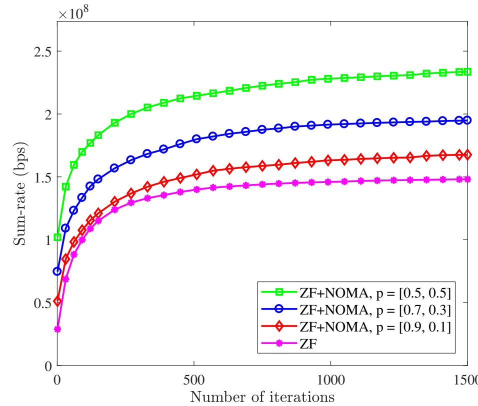

Fig. 4. Sum-rate versus the number of iterations for ZF+NOMA.

results verify that the proposed coalition game algorithms can provide near-optimal solutions with low complexity. The final state achieves a significant improvement of the overall sum-rate compared with previous schemes, while also increases the number of users being served simultaneously. A potential future work is to also examine the power coefficients of each NOMA pair to ensure fairness among the rates of the users.

Acknowledgment

This work has been partially supported by the H2020-MSCA-ITN-2016 framework under grant agreement number 722788 (SPOTLIGHT) and partially co-funded by the European Regional Development Fund and the Republic of Cyprus through the Research Promotion Foundation, under the project INFRASTRUCTURES/1216/0017 (IRIDA).

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