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Three-Step Optimization Algorithm in SCMA-based System for User Association and Resource Allocation in C-RAN

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Abstract—**In this paper, downlink user association, codebook assignment, and power allocation for a Sparse Code Multiple Access (SCMA)-based communication in Cloud Radio Access Network (C-RAN) are interrogated. The main aim of this paper is to accomplish a three-step resource allocation algorithm to achieve the maximum total sum rate subject to SCMA, user association, minimum user power, total available power in Radio Remote Head (RRH), and fronthual constraints with low complexity. To solve the recommended problem an iterative algorithm considering Successive Convex Approximation is utilized. The main problem is separated into three subproblems of user association, codebook assignment, and power allocation. The user association and codebook assignment subproblems are Integer Linear Programming and solved with CVX toolbox. Furthermore, to solve the power allocation subproblem, Successive Convex Approximation with Low Complexity is applied. In the simulation results, the effectiveness of the recommended resource allocation method is shown and compared to OFDMA.**

Keywords—C-RAN; Optimization; Resource Allocation; SCMA; 5G.

I. INTRODUCTION

In recent years, due to the widespread use of smartphones and their many applications in human life, we need high-speed wireless communications and network architecture that can support a large number of users [1]. However, current cellular network architecture was not initially designed for such abilities. Cloud Radio Access Network (C-RAN) [2] has been recently introduced as a new architecture for upgrading former cellular architecture to support high data traffic and reduce capital consumption and working cost. C-RAN can separate computational functionalities from distributed Base Stations (BSs) into a centralized processing center by merging them. A typical C-RAN is made out of (i) light-weight, distributed Radio Remote Heads (RRHs) in addition to reception apparatuses, which are situated at the remote site and are controlled by a brought together virtual base station pool, (ii) the Base Band Unit (BBU) made out of fast programmable processors and real-time virtualization technology to do digital processing errands, and collection of them called the BBU pool, and (iii) low-latency high data transfer capacity fronthaul links, which interface the RRHs to the BBU pool [2]-[4].

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To counteract quickly developing interest, next-generation wireless access networks must support high spectral efficiency. To address these challenges, recently Non-Orthogonal Multiple Access (NOMA) [5] has been introduced. NOMA was introduced as the Multiple Access (MA) technique to enhance the spectral efficiency of mobile communication networks by more convenient use of subcarriers [6]. Different from ordinary Orthogonal Multiple Access (OMA) plans, NOMA presents some controllable interferences to recognize overloading at the receiver that increases receiver complexity. In like manner, higher spectral efficiency and massive connectivity can be practiced by NOMA for 5G [7], [8].

Sparse Code Multiple Access (SCMA) is a code domain NOMA technique which can enhance spectral efficiency of wireless networks [9]. In SCMA, bitstreams are mapped to different sparse codewords. By utilizing the sparsity of codewords, at the receiver, Multi-User Detection (MUD) depend Message Passing Algorithm (MPA) [10]. MPA can be utilized to isolate symbols with satisfactory complexity [5], [9], [11].

A. Related Works

In [12], the authors are considered codebook (that codebooks illustrate users) assignment to subcarriers as a matching game, and power allocation is solved with the water-filling algorithm in the SCMA-based system to maximizing sum rate in uplink transmission. In [13], a strategy for codebook assignment and power allocation is contemplated where joint system energy efficiency and sum rate are maximized. In [14], the authors are investigated resource allocation in a Device to Device (D2D) communication-based cellular network for an SCMA-based system. The authors are suggested a joint power and codebook allocation procedure in [15] for an SCMA-based Heterogeneous cellular Network (HetNet) to maximize total sum rate. Also, Power Domain NOMA (PD-NOMA) is contemplated with SCMA from total sum rate and complexity facets. The authors of [16] are investigated user association, codebook assignment, and beamforming for Multiple Input Single Output (MISO)-based system in C-RAN. An SCMA-based edge computing scheme is recommended for Internet-of-Things (IoT) systems in [17]. The authors of [18] are recommended a resource allocation framework for maximizing throughput by considering a given transmit power and delay constraint for a single-cell SCMA wireless network with multiple users for haptic users. A cooperative NOMA scheme is studied in [19] to increase reliability and coverage. The resource allocation in traditional Orthogonal Frequency Division Multiple Access (OFDMA)-based system is considered using BS-assignment based on the biggest average received signal strength from the BS at each user in [20]. The joint channel, cell, and power allocation in multi-cell relay networks are interrogated in [21], where every client is assigned to the BS with the highest channel gain. In [22], the authors are investigated an energy-efficient resource allocation problem for a multi-cell OFDMA network in a customary wireless network. Also, the accessible estimations of Channel State Information (CSI) are imperfect. The authors in [23] are recommended a centralized radio resource allocation algorithm to maximize the system sum rate in the OFDMA-based multicell system. In [24], by considering effective capacity, an optimal power allocation method is recommended in which the impact of the deferral Quality of Service (QoS) on the power portion and gain from content caching is assessed. The problem of resource allocation for a downlink multi-user Orthogonal Frequency Division Multiplexing (OFDM) system to maximize the effective energy efficiency and effective capacity is investigated in [25]. In [26], the Authors are focused on subcarrier and power allocation for an OFDMA full-duplex (FD) system with A three-step algorithm to maximize the sum-rate of the system subject to individual rate constraints at the uplink and downlink users, and transmit power constraints at the base station (BS) and uplink users.

B. Contribution

According to our awareness, no former works have investigated the user association, codebook assignment, and power allocation for C-RAN with the following constraints and compared to OFMDA with a three-step low complexity resource allocation algorithm so far. In this paper, we study user association, codebook assignment, and power allocation for downlink SCMA in C-RAN to maximize the total sum rate.

Our principle contributions are abridged as pursues:

1) We formulate the resource allocation optimization problem to maximize the total sum rate using SCMA in C-RAN considering the fronthaul capacity constraint, the RRHs and user's power constraints, the SCMA constraint, and the users association constraints. Also, we introduce three parameters for user association, codebook assignment, and power allocation to simplify the resource allocation optimization problem.

2) To solve the resource allocation problem according to Alternate Search Method (ASM) [15], [16], [27]–[29], first, the problem is divided into three subproblems of user association, codebook assignment, and power allocation. The user association subproblem was solved with fixed codebook assignment and power allocation. To solve the codebook assignment subproblem, we consider user association and power allocation subproblems as a constant. In the third subproblem for fixed user association and codebook assignment, power allocation is solved by applying Successive Convex Approximation with Low Complexity (SCALE) [15], [29]–[31].

3) Using simulations, we can see the difference between the performance of SCMA and OFDMA in C-RAN. Using the SCMA, we can achieve the best performance.

The rest of this paper is classified as pursues. Section II portrays our system model and problem formulation. In section III, the analytical solution for our problem, convergence analysis, and optimality statement are provided. Section IV represents the simulation results of our proposed algorithm. At long last, Section V concludes this paper.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. System Model

A downlink multi-cell SCMA-based system is considered for C-RAN as shown in Fig. 1. In this system model, a set of mobile users are specified by $\mathrm{U}=\{1,2,\cdots,U\}$. The RRH separates the achievable bandwidth W into a set of subcarriers, indicated by $\mathrm{S}=\{1,2,\cdots,S\}$ and $\mathrm{M}=\{1,2,\cdots,M\}$ are collection of codebooks. We denote the set of RRHs (cells) by $\mathrm{N}=\{1,2,\cdots,N\}$. In this system model, we consider that each cell has one RRH [32]. $c_{i,j}^{k}\in\{0,1\}$ is the codebook assignment parameter. If this value is equal to one ($c_{i,j}^{k}=1$), it means assigning the ith codebook to j th user in RRH k and if it is zero ($c_{i,j}^{k}=0$), it means that no assignment has been made. We define an association variable $r_{j,k}\in\{0,1\}$ with $r_{j,k}=1$ if user j is associated to RRH k, and $r_{j,k}=0$ if it is not associated to RRH k. Also, all parameters defined in this paper are presented in Table I. The signal to interference plus noise ratio (SINR) of j th user on i th codebook for RRH k is defined as follows [13], [15], [28], [29]:

$$SINR_{i,j}^{k}=\frac{p_{i,j}^{k}\sum_{s=1}^{S}a_{s,i}\,|h_{s,j}^{k}|^{2}}{\sum_{\substack{k'=1\\k'\neq k}}^{N}\sum_{\substack{j'=1\\j'\neq j}}^{U}p_{i,j'}^{k'}\sum_{s=1}^{S}a_{s,i}\,|h_{s,j}^{k'}|^{2}+(\sigma_{i,j}^{k})^{2}},\qquad(1)$$

In (1), $a_{s,i}$ represents the subcarriers associated with each codebook, if this value is equal to one, it means the subcarrier s is assigned to the ith codebook and else if it is zero, illustrated in Fig. 2. The channel coefficient of user j on subchannel s for RRH k is illustrated by $h_{s,j}^{k}$, and $p_{i,j}^{k}$ is the power allocated to the j th user on ith codebook in RRH k. $(\sigma_{i,j}^{k})^{2}$ is the variance of the Additive White Gaussian Noise (AWGN) for the ith codebook and the jth user in kth RRH. By considering (1), the maximum achievable rate of jth user on ith codebook for RRH k can be defined as follows [13], [15], [28], [29]:

$$R_{i,j}^{k}=\log_{2}(1+SINR_{i,j}^{k}).\qquad(2)$$

In SCMA structure, codebooks are defined in a way that each codebook includes C codewords of length S and number of nonzero components in each codeword is z. The number of zero components of each codeword which is more than it's non-zero components make codewords sparse. In the transmitter side, any $\log_2 C$ bits for user j are mapped to a sparse codeword from the ith codebook, and then U codewords are multiplexed over S shared orthogonal resources (such as OFDMA subcarriers). M is the most number of codebooks that can be obtained with a combination function of z and S [9].

The ideal fronthaul is an optical fiber, but due to limitations in the use of optical fiber, other methods of communication such as wireless communication are used. Wireless communications have capacity limitations, so if using a wireless fronthaul in the system model, it is necessary to consider fronthaul capacity constraint [33]. The proposed system model in this paper uses wireless communication for the fronthaul.

B. Problem Formulation

In this section, we proposed the optimization problem for resource allocation to maximize the total sum rate as follows:

$$\begin{aligned}
&\max_{r_{j,k},c_{i,j}^{k},p_{i,j}^{k}}\ \sum_{k=1}^{N}\sum_{i=1}^{M}\sum_{j=1}^{U}r_{j,k}c_{i,j}^{k}R_{i,j}^{k}\\
&s.t.: C1:\sum_{k=1}^{N}r_{j,k}\le 1,\ \ \forall j\in\mathrm{U},\\
&C2:\sum_{i=1}^{M}\sum_{j=1}^{U}r_{j,k}c_{i,j}^{k}a_{s,i}\le D_{c},\ \ \forall k\in\mathrm{N},s\in\mathrm{S},\\
&C3:\sum_{i=1}^{M}\sum_{j=1}^{U}r_{j,k}c_{i,j}^{k}R_{i,j}^{k}\le R_{max}^{k},\ \ \forall k\in\mathrm{N},\\
&C4:\sum_{i=1}^{M}\sum_{j=1}^{U}r_{j,k}c_{i,j}^{k}p_{i,j}^{k}\le P_{max}^{k},\ \ \forall k\in\mathrm{N},\\
&C5: p_{i,j}^{k}\ge 0,\ \ \forall j\in\mathrm{U},i\in\mathrm{M},k\in\mathrm{N},\\
&C6: r_{j,k}\ge c_{i,j}^{k},\ \ \forall j\in\mathrm{U},i\in\mathrm{M},k\in\mathrm{N},\\
&C7: c_{i,j}^{k}\in\{0,1\},\ \ \forall j\in\mathrm{U},i\in\mathrm{M},k\in\mathrm{N},\\
&C8: r_{j,k}\in\{0,1\},\ \ \forall j\in\mathrm{U},k\in\mathrm{N},
\end{aligned}\qquad(3)$$

In (3), the objective is to find the best allocation of codebooks, users, and power to maximize the total sum rate. $C1$ indicates the maximum RRH assigned to each user. Due to the interference definition, we must use the $C1$ constraint for user association [28], [34]. $C2$ specifies the maximum subcarrier reuse in each cell (SCMA constraint) [9], [13], [15], [29]. $C3$ is the fronthual capacity limitation for each RRH [3], [32]–[34]. $C4$ shows the maximum power available for each RRH [32], [34]. The $C5$ constraint is used to

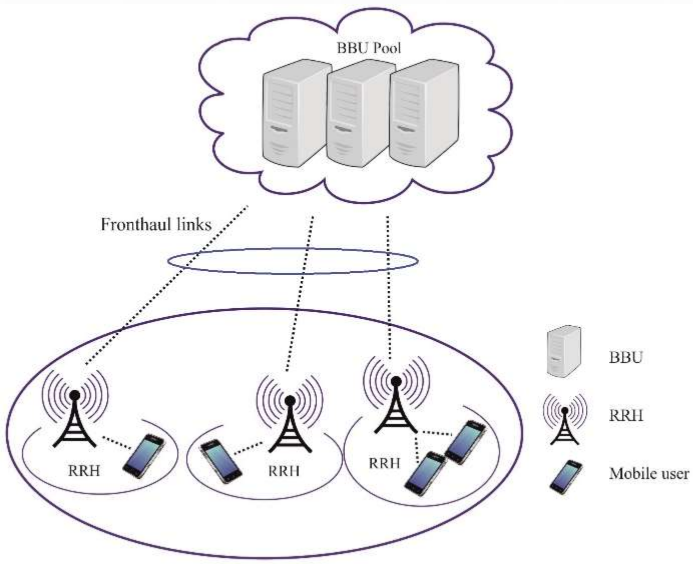

Figure 1. A system model of the C-RAN.

TABLE I. PARAMETERS DEFINITION

Definition	Parameter
Set of mobile users	$\mathcal{U}$
Number of mobile users	U
Total available Bandwidth	W
Set of subcarriers	$\mathcal{S}$
Number of subcarriers	S
Collection of codebooks	$\mathcal{M}$
Number of codebooks	M
Set of RRHs	$\mathcal{N}$
Number of RRHs	N
Codebook assignment parameter	$c_{i,j}^k$
User association parameter	$r_{j,k}$
SINR of j th user on i th codebook for RRH k	$SINR_{i,j}^k$
Subcarriers association	$a_{s,i}$
Channel coefficient of user j on subchannel s for RRH k	$h_{s,j}^k$
Power allocated to the j th user on i th codebook for RRH k	$p_{i,j}^k$
AWGN for the i th codebook and the j th user in k th RRH	$(\sigma_{i,j}^k)^2$
Rate of j th user on i th codebook for RRH k	$R_{i,j}^k$
Number of codewords	C
Number of nonzero components of each codeword	z
Maximum number of subcarriers reuse	D_c
Fronthaul capacity limitation for each RRH	R_{max}^k
Maximum power available for each RRH	P_{max}^k
Tolerance for convergence	ϵ , ε
SCALE variable	α , β
Lagrange multipliers	λ, ψ, μ
Sub-gradient method step size	$\varsigma_1, \varsigma_2, \varsigma_3$
Path loss exponent	ζ
Rayleigh fading for user j and RRH k on codebook i	$x_{i,j}^k$
Distance between user j and RRH k on codebook i	$d_{i,j}^k$

express the minimum power allocated to each user [13], [15], [29]. $C6$ imposes $c_{i,j}^k = 0 \,\forall j \in \mathcal{U}, i \in \mathcal{M}, k \in \mathcal{N}$ if $r_{j,k} = 0 \;\; \forall j \in \mathcal{U}, k \in \mathcal{N}$, i.e., the RRH k is not

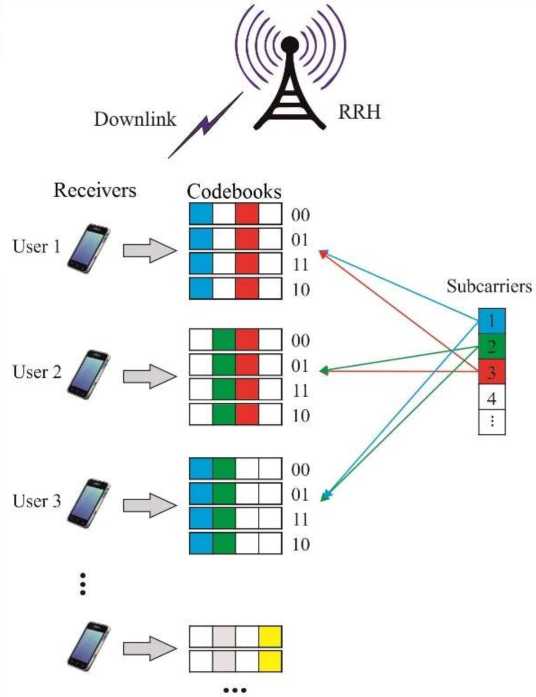

Figure 2. The SCMA-based system in each cell.

transmitting. $C7$ and $C8$ implies binary variable that indicates the codebook allocation and user association.

Due to inter-cell interference, the optimization problem (3) has a non-convex objective function and constraints [36]. Also the optimization problem (3) includes non-linear constraints with a mix of binary and continuous variables and its simple solution is not possible [36]. Direct problem solving involves searching among all the possibilities for user association and codebook assignment, along with the allocation of power for each of them. Due to the complexity of the exhaustive search, it's not practical. Therefore the optimization problem (3) belongs to nonconvex and the NP-hard optimization problem category [37-38]. Therefore, the proposed optimization problem cannot be solved optimally through conventional methods. To solve the optimization problem (3), we proposed the ASM approach wherein the problem is divided into three subproblems of user association, codebook assignment, and power allocation. In the codebook assignment subproblem, user association and power allocation are considered constant. In the second subproblem, by considering the codebook assignment and power allocation are fixed, users are associated. In the third subproblem, by considering user association and codebook assignment, power allocation was solved with SCALE. Solving the subproblems will continue intermittently until convergence is accomplished. An overview of the proposed algorithm for solving the optimization problem (3) is summarized in Algorithm 1.

Also, in Algorithm 1 to the initialization of transmit powers ($p(0)$), we apply a uniform power allocation among all users, meaning that maximum available powers for each RRHs are equally divided among all users [15-16], [28-29]. When we assume the initial power distribution is uniform, we give all codebooks a chance to check to find the best assignment. Therefore, the answer obtained in this way is the best and the fastest possible answer. By different initial choices for power, the overall convergence time of the proposed algorithm increases, and on the other hand, no equal chance to check all the codebooks and as a result, no proper answer will be obtained. Also, $r(0)$ has a random structure. In the following, the recommended solution of codebook assignment, user association, and power allocation subproblems will be clarified.

III. The Proposed Algorithm

A. Codebook Assignment Subproblem

Codebook assignment subproblem by considering fixed user association and power allocation is suggested as follows:

$$\begin{aligned}
&\max_{c_{i,j}^k} \sum_{k=1}^{N}\sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^k R_{i,j}^k \\
&s.t.: C2: \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^k a_{s,i} \le D_c,\ \ \forall k \in \mathrm{N}, s \in \mathrm{S}, \\
&C3: \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^k R_{i,j}^k \le R_{max}^k,\ \ \forall k \in \mathrm{N}, \\
&C4: \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^k p_{i,j}^k \le P_{max}^k,\ \ \forall k \in \mathrm{N}, \\
&C6: r_{j,k} \ge c_{i,j}^k,\ \ \forall j \in \mathrm{U}, i \in \mathrm{M}, k \in \mathrm{N}, \\
&C7: c_{i,j}^k \in \{0,1\},\ \ \forall j \in \mathrm{U}, i \in \mathrm{M}, k \in \mathrm{N},
\end{aligned} \tag{4}$$

In (4), the optimization variable is $c_{i,j}^k$. As we know, $c_{i,j}^k$ is a binary variable. Then the objective function of optimization problem (4) and constraints are in Integer Linear form [15-16], [29], [32]. Therefore, the optimization problem (4) is an Integer Linear Programming (ILP) problem. To solve it, we can apply achievable software such as MOSEK [35]. MOSEK is a software that can solve optimization problems. Also, it can be used with CVX in MATLAB for solving optimization problems [35].

B. User Association Subproblem

User association subproblem, by considering a fixed codebook assignment and power allocation is mentioned as follows:

$$\begin{aligned}
&\max_{r_{j,k}} \sum_{k=1}^{N}\sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^k R_{i,j}^k \\
&s.t.: C1: \sum_{k=1}^{N} r_{j,k} \le 1,\ \ \forall j \in \mathrm{U},
\end{aligned}$$

$$C2: \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^{k} a_{s,i} \le D_c, \ \ \forall k \in \mathrm{N}, s \in \mathrm{S},$$

$$C3: \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^{k} R_{i,j}^{k} \le R_{max}^{k}, \ \ \forall k \in \mathrm{N},$$

$$C4: \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^{k} p_{i,j}^{k} \le P_{max}^{k}, \ \ \forall k \in \mathrm{N},$$

$$C6: \ r_{j,k} \ge c_{i,j}^{k}, \qquad \forall j \in \mathrm{U}, i \in \mathrm{M}, k \in \mathrm{N},$$

$$C8: \ r_{j,k} \in \{0,1\}, \qquad \forall j \in \mathrm{U}, k \in \mathrm{N}, \tag{5}$$

Like the previous section, in (5), the optimization variable is $r_{j,k}$. As we know, $r_{j,k}$ is a binary variable. Then the objective function of optimization problem (5) and constraints are in Integer Linear form [15-16], [29], [32]. Therefore, the optimization problem (5) is an ILP problem. To solve it, we can utilize available software such as MOSEK [35].

C. Power Allocation

Given the user association and codebook assignment, the power allocation subproblem is formulated as follows:

$$\max_{p_{i,j}^{k}} \sum_{k=1}^{N}\sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^{k} R_{i,j}^{k}$$

$$s.t.: C3: \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^{k} R_{i,j}^{k} \le R_{max}^{k}, \ \ \forall k \in \mathrm{N},$$

$$C4: \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^{k} p_{i,j}^{k} \le P_{max}^{k}, \ \ \forall k \in \mathrm{N},$$

$$C5: p_{i,j}^{k} \ge 0, \qquad \forall j \in \mathrm{U}, i \in \mathrm{M}, k \in \mathrm{N}, \tag{6}$$

To tackle the non-convexity issue of the target function and $C3$, SCALE is applied [30]. To exert SCALE approximation the following inequality is utilized [30], [36]:

$$\log(1+\Xi) \ge \alpha \log(\Xi) + \beta, \tag{7}$$

where:

$$\alpha = \frac{\bar{\Xi}}{1+\bar{\Xi}}, \quad \beta = \log(1+\bar{\Xi}) - \alpha \log(\bar{\Xi}). \tag{8}$$

where Ξ and $\bar{\Xi}$ are SINR in n^{th} and $n-1^{th}$ iteration, respectively. By transforming $p_{i,j}^{k} = exp(\tilde{p}_{i,j}^{k})$, the optimization problem (6) is reformulated as pursues:

$$\max_{\tilde{p}_{i,j}^{k}} \sum_{k=1}^{N}\sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^{k} (\alpha_{i,j}^{k} \log(SINR_{i,j}^{k}) + \beta_{i,j}^{k})$$

$$s.t: C3: \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^{k} (\alpha_{i,j}^{k} \log(SINR_{i,j}^{k}) + \beta_{i,j}^{k}) \le R_{max}^{k}, \quad \forall k \in \mathrm{N},$$

$$C4: \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^{k} exp(\tilde{p}_{i,j}^{k}) \le P_{max}^{k}, \ \ \forall k \in \mathrm{N},$$

$$C5: exp(\tilde{p}_{i,j}^{k}) \ge 0, \qquad \forall j \in \mathrm{U}, i \in \mathrm{M}, k \in \mathrm{N}, \tag{9}$$

Optimization problem (9) is a convex optimization problem [15], [29], [30].

***Proof*:** Objective function and non-convex constraint in optimization problem (6) transform to log-sum-exp in optimization problem (9) [36]. Then problem (9) is a convex optimization problem [36].

To solve (9), we used the dual method [36]. The dual method for optimization problem (9) written as follows:

$$\ell(\tilde{p}_{i,j}^{k}, \lambda, \mu) =$$
$$\sum_{k=1}^{N}\sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k} c_{i,j}^{k} (\alpha_{i,j}^{k} \log(SINR_{i,j}^{k}) + \beta_{i,j}^{k})$$
$$+\sum_{k'=1}^{N} \mu_{k'} (R_{max}^{k'} - \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k'} c_{i,j}^{k'} (\alpha_{i,j}^{k'} \log(SINR_{i,j}^{k'}) + \beta_{i,j}^{k'}))$$
$$+\sum_{k''=1}^{N} \lambda_{k''} (P_{max}^{k''} - \sum_{i=1}^{M}\sum_{j=1}^{U} r_{j,k''} c_{i,j}^{k''} exp(\tilde{p}_{i,j}^{k''})). \tag{10}$$

where $\ell(\tilde{p}_{i,j}^{k}, \lambda, \mu, \psi)$ is lagrangian function of the optimization problem (9), and λ, μ, ψ are Lagrange coefficients or dual variables [36]. Therefore the dual problem is written as follows:

$$\min_{\lambda,\mu} \ g(\lambda,\mu) = \max_{\tilde{p}_{i,j}^{k}} \ \ell(\tilde{p}_{i,j}^{k}, \lambda, \mu)$$

$$s.t: \ \lambda, \mu \pm 0 \tag{11}$$

Based on convex optimization for simplifying instead of solving the main problem, we can solve the dual problem [36]. Therefore in (11), a dual problem as explained in [36] was obtained. Then we can solve the optimization problem (11) instead of (9) [36]. The dual problem can be obtained by solving the Lagrangian function with respect to the main optimization variable.

In dual method, it should be noted, if the main problem is a maximization problem, the dual problem is converted to a minimization problem and conversely. Also, dual variables are optimization variables in the dual problem [36].

By deriving the Lagrange function and equating the derivative with zero, $p_{i,j}^{k}$ can be obtained as follows:

$$p_{i,j}^k = \left(\frac{\alpha_{i,j}^k (1-\mu_k)}{\lambda_k + A_{i,j}^k - B_{i,j}^k} \right)^+,$$

$$A_{i,j}^k = \frac{\sum_{\substack{k'=1 \\ k'\neq k}}^{N} \sum_{\substack{j'=1 \\ j'\neq j}}^{U} r_{j',k} c_{i,j'}^{k'} \alpha_{i,j'}^{k'} \sum_{s=1}^{S} a_{s,i} | h_{s,j}^{k'} |^2}{\sum_{\substack{k'=1 \\ k'\neq k}}^{N} \sum_{\substack{j'=1 \\ j'\neq j}}^{U} p_{i,j'}^{k'} \sum_{s=1}^{S} a_{s,i} | h_{s,j}^{k'} |^2 + (\sigma_{i,j}^k)^2},$$

$$B_{i,j}^k = \frac{\sum_{\substack{l=1 \\ l\neq k}}^{N} \mu_l \sum_{\substack{r=1 \\ r\neq j}}^{U} r_{r,l} c_{i,r}^l \alpha_{i,r}^l \sum_{s=1}^{S} a_{s,i} | h_{s,j}^l |^2}{\sum_{\substack{l=1 \\ l\neq k}}^{N} \sum_{\substack{r=1 \\ r\neq j}}^{U} p_{i,r}^l \sum_{s=1}^{S} a_{s,i} | h_{s,j}^l |^2 + (\sigma_{i,j}^k)^2}. \quad (12)$$

The dual problem is solved by the subgradient method [39]. The dual variables are updated by applying the (13) formula with respect to (12). In (13) ς_1, ς_2, and ς_3 are sub-gradient method step size [39]. Since the dual problem is always a convex optimization problem, the sub-gradient method will converge to the globally optimal solution [39].

$$\lambda_k^{(m+1)} = [\lambda_k^{(m)} - \varsigma_1 (P_{max}^k - \sum_{i=1}^{M} \sum_{j=1}^{U} r_{j,k} c_{i,j}^k exp(\tilde{p}_{i,j}^k))]^+,$$

$$\mu_k^{(m+1)} = [\mu_k^{(m)} - \varsigma_3 (R_{max}^k - \sum_{i=1}^{M} \sum_{j=1}^{U} r_{j,k} c_{i,j}^k (\alpha_{i,j}^k \log_2(SINR_{i,j}^k) + \beta_{i,j}^k))]^+ \quad (13)$$

D. Convergence Analysis

For explaining the convergence of the recommended algorithm mentioned in Algorithm 1, the following theorem is utilized.

Theorem: By using the iterative approach mentioned in Algorithm 1, after any iteration, the objective function of problem (3) improves in comparison with the last iteration, and after a finite number of iterations converges.

Proof. If we consider $Obj(c,r,p)$ is equal to $Obj(c,r,p) = \sum_{k=1}^{N} \sum_{i=1}^{M} \sum_{j=1}^{U} r_{j,k} c_{i,j}^k R_{i,j}^k$, then to guarantee the convergence we need to have (14) equation.

In (14), inequality (1) and (2) illustrates that for fixed user association and power allocation, and codebook assignment and power allocation, the solution of iteration t+1 is better or equal to that of iteration t. Due to user association and codebook assignment is ILP [35-36], [39]. Accordingly, we have

ALGORITHM 1

Three-Step Iterative Algorithm

I. Initialize: Set t = 0, initialize $p(0)$, $r(0)$ and $\varepsilon > 0$,

II. **Repeat**

A) Codebook Assignment:
Set $p = p(t)$, $r = r(t)$ and find the solution of (4) problem using CVX with fixed power and assign its solution in to $c(t+1)$,

B) User Association:
Set $p = p(t)$, $c = c(t)$ and find the solution of (4) problem using CVX with fixed power and assign its solution in to $r(t+1)$,

C) Power Allocation

C.1) Initialization for Step C): Set $n = 0$, $p(t)^o = p(t)$, $\alpha = 1$ and $\beta = 0$,

C.2)

1) Initialization for Step C.2): Set $m = 0$ and initialize $\lambda^{(0)}$, $\mu^{(0)}$, $\psi^{(0)}$ and $\grave{o}_1$ ($0 \le \grave{o}_1 < 1$),

2) Compute p according to (12),

3) Update λ, μ and ψ with subgradient method by using (13),

4) When $\| \lambda^{(m)} - \lambda^{(m-1)} \| \le \grave{o}_1$, $\| \mu^{(m)} - \mu^{(m-1)} \| \le \grave{o}_1$ and $\| \psi^{(m)} - \psi^{(m-1)} \| \le \grave{o}_1$, stop and go to C.3). Otherwise, set m = m + 1 and go back to 2)

C.3) Update α and β according to (8),

C.4) When $n = N_{max}$ or convergence, stop. Otherwise, set $n = n+1$ and go back to C.2),

Until{Convergence within the tolerance ε}

$$\ldots \le Obj(c^t, r^t, p^t) \le^1 Obj(c^{t+1}, r^t, p^t) \le^2 Obj(c^{t+1}, r^{t+1}, p^t) \le^3 Obj(c^{t+1}, r^{t+1}, p^{t+1}) \le \ldots \quad (14)$$

$$Obj(c^t, r^t, p^t) \le^1 Obj(c^{t+1}, r^t, p^t) \le^2 Obj(c^{t+1}, r^{t+1}, p^t). \tag{15}$$

For inequalities (3) because the optimization problem (9) is convex, a similar reason as utilized for inequality (1) and (2) can be exploited [27], [40]. The final power allocation subproblem is a convex optimization problem in which the optimal value at any iteration is accomplished. Because at any iteration, the approximation parameters refresh based on the results of the previous iteration, the results of the solution and the objective function value in any iteration are improved or stay fixed in consideration to the past iteration [35-36], [39].

E. Optimality Statement

In [28], the authors are investigated the optimality gap for the ASM method for a simple network structure for the proposed system model in simulation.

IV. Simulation Results

Numerical results are obtained for a downlink SCMA-based C-RAN system with different parameters. The RRHs are located at the center of each cell and the users are randomly distributed around them. $h_{i,j}^k = x_{i,j}^k (d_{i,j}^k)^{\zeta}$ and ζ demonstrates the path loss exponent and $\zeta = -3$, $x_{i,j}^k$ illustrates the Rayleigh fading, and $d_{i,j}^k$ shows the distance between user j and RRH k on codebook i. There exist four RRHs with a 250 m radius. $D_c = 2$, $z = 2$, and $R_{max}^k = 50\,\text{bps/Hz}\ \forall k \in \mathrm{N}$ in all simulations. Also, all simulation parameters are explained in Table II.

TABLE II. SIMULATION PARAMETERS VALUE

Parameter	Value
U	8, 12
S	4
M	6
N	4
$(\sigma_{i,j}^k)^2$	$-174 dbm/Hz\ \forall j \in \mathrm{U}, i \in \mathrm{M}, k \in \mathrm{N}$
z	2
D_c	2
R_{max}^k	$50\,\text{bps/Hz}\ \forall k \in \mathrm{N}$
P_{max}^k	40 *Watts*
ò , ò̧	10^{-5}
ζ	-3
$d_{i,j}^k$	250 m

Also, to simulate the paper, Algorithm 1 mentioned in section III is used step by step. Table II is also used to quantify the parameters. Furthermore, we use MATLAB software for the simulation of our proposed system model and simulation obtained with 500 Monte Carlo iterations [43]. In this paper to show preference the proposed scheme, we compared it to OFDMA [26]. In the OFDMA simulation for evaluation, we use all conditions and assumptions in the proposed system model. In other words, all parameters defined in Table II were used for OFDMA except SCMA parameters

Fig. 3 illustrates total sum rate versus number of users. As it is seen, the total sum rate increases as number of users increases, as we expected. The figure also demonstrates the total sum rate versus number of users for OFDMA. According to Fig. 3, it can be seen that at the same subcarrier and P_{max}^k, SCMA performance is better than OFDMA, about 25% total sum rate increases. Also, to show the impact of the P_{max}^k on network performance, the total sum rate versus number of users for different P_{max}^k is shown in this figure.

Fig. 4 shows total sum rate in terms of the maximum available power for each RRH. In this figure, SCMA is compared to OFDMA in C-RAN, and as seen, SCMA is better than OFDMA. Based on simulation results, total sum rate in average 10% increases. As we expected, due to the more suitable use of the subcarriers, the SCMA will achieve a higher total sum rate than OFDMA. Also in Fig. 4, the total sum rate in terms of maximum available power for each RRH with a distinct number of users and versus multiple access methods are shown. As can be seen, total sum rate increases as number of users increases.

V. Conclusions

In this paper, SCMA is utilized as a multiple access method for C-RAN. The motivation behind this paper is the user association, codebook assignment, and power allocation to maximize the total sum rate in C-RAN with a low complexity algorithm by considering C-RAN, SCMA, user association, and power constraints. To solve the recommended problem, we administer the iterative algorithm considering SCA. For this purpose, we utilized the ASM method that in any iteration the user association, codebook assignment, and power allocation subproblems are solved independently and the algorithm is continued until convergence is attained. Simulation results also demonstrate that the recommended resource allocation in C-RAN with the mentioned constraints has better performance than OFDMA. Therefore, one of the considerable challenges of the 5G networks is to apply proper multiple access methods, which, according to the results of this study, SCMA is the best solution for

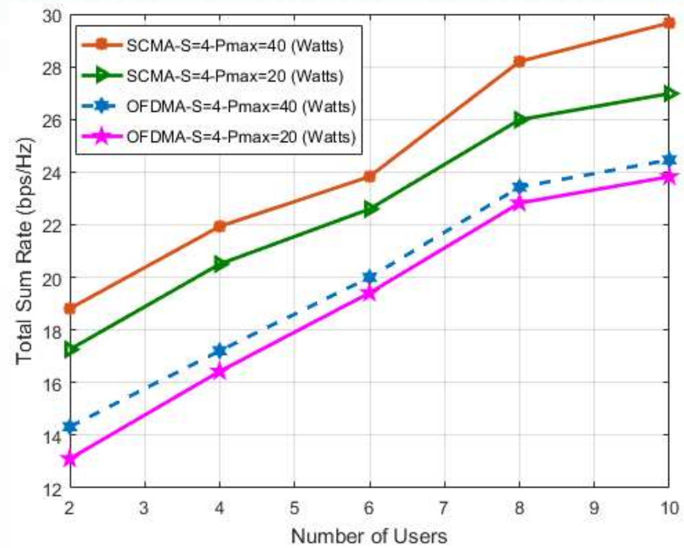

Figure 3. Sum rate versus different number of users for different Pmax.

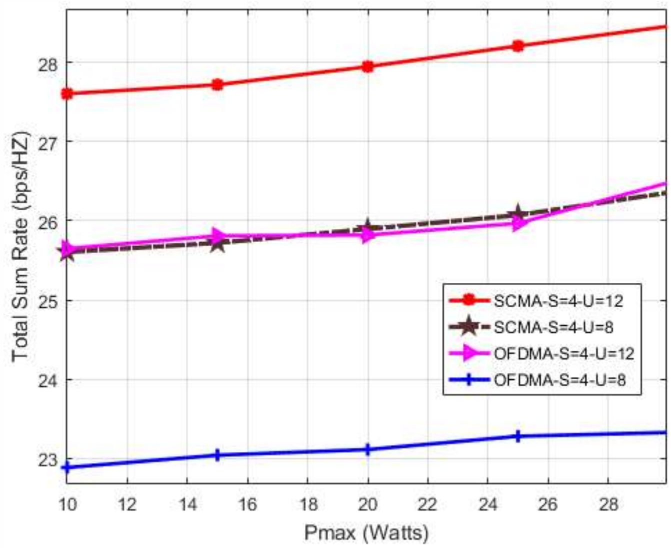

Figure 4. Sum rate versus different Pmax for different number of users.

this issue. In future works, we suggest focusing on analyzing complexity for the proposed algorithm, considering delay, and considering Machine learning to resource allocation in the proposed system model.

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