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Joint RRH-Association, Sub-Channel Assignment and Power Allocation in Multi-Tier 5G C-Rans

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ABSTRACT Multi-tier cloud-radio access networks (C-RANs) have been suggested as a promising network model in fifth generation wireless networks to provide high data rate, high spectral efficiency, and high energy efficiency at low cost. However, to achieve the potential benefits of multi-tier C-RANs, it is important to design efficient resource allocation algorithms provided that the data rate of users is guaranteed. Therefore, in this paper, we considered the joint optimization of remote-radio-heads (RRH) association, sub-channel assignment, and power allocation for network sum-rate maximization in single-carrier frequency division multiple access (SC-FDMA)-based multi-tier C-RAN. Due to the exclusivity and adjacency constraints of SC-FDMA, the resource allocation problem becomes harder to solve, thus, the optimal solution is difficult for reasonably sized network. Therefore, we propose an iterative algorithm that solves this non-linear mixed-integer problem in two steps wherein the first step, power allocation and subchannel assignment are carried out, while the second step of the proposed algorithm is concerned with the RRH-association. The iterative algorithm converges to efficient solution. The simulation results verify the effectiveness of our proposed algorithm.

INDEX TERMS C-RAN, multi-tier networks, SC-FDMA, sum-rate maximization, resource allocation, RRH-association.

I. INTRODUCTION

It is foreseen that by 2020, cellular wireless networks will have to deal with 1000 fold data traffic in comparison with today's traffic volume [1]. Moreover, a huge number of mobile gadgets with a widespread applications range and data-rate constraints are also expected. Thus, the fifth-generation (5G) multi-tier cellular wireless networks are advised where different network tiers co-exist, e.g., small cells (i.e., picocells and femtocells) are underlayed in the conventional macrocell to enhance the capacity and coverage of the macro base-station (BS) networks as shown in Fig. 1. However, the co-existence of different network tiers and sharing the same resources result in interference among them which may result in avoiding the goals of 5G. Therefore, a well capable centralized mechanism is required which can efficiently allocate resources to different network tiers in order to achieve the envisioned goals of 5G [2].

To address the above challenges regarding multi-tier networks, a new mechanism known as cloud-radio access network (C-RAN) has been proposed by the researchers which consists of two parts; a group of remote-radio-heads (RRHs) part and a centralized-baseband-unit (BBU)-pool part [3]. The RRHs and BBU-pool are interconnected through the fronthaul links while macrocell BS (MBS) is connected with core networks through backhaul links. The BBU pool executes upper layer functions and baseband signal-processing, whereas, the RRHs normally perform as radio-frequency (RF) transceivers and only perform basic RF functions [4], [5]. C-RAN has the ability to increase network-capacity and energy-efficiency, reduce the network capital and operating expenditures and manage the inter-tier and the inter-cell interference [6]. These benefits of 5G multi-tier networks can be achieved if small cells are deployed densely in a C-RAN architecture.

Single-Carrier Frequency Division Multiple-Access (SC-FDMA) is the suitable uplink (UL) multiple-access technique considered in the Third-Generation Partnership Project-Long Term Evolution (3GPP-LTE) standard [7].

SC-FDMA is more appropriate for UL communication because it shows low peak-to-average power ratio (PAPR) as compared to the Orthogonal Frequency Division Multiple-Access (OFDMA). SC-FDMA can be implemented in two ways: localized or constrained SC-FDMA and distributed SC-FDMA. In localized or constrained SC-FDMA, each user transmits its symbols on a set of contiguous subchannels while in distributed SC-FDMA, the subchannels are spread over the entire signal band. References [8] and [9] show that constrained SC-FDMA results in higher throughput as compare to the distributed one. Therefore, we employ constrained SC-FDMA for UL in Heterogeneous C-RAN. Localized or constrained SC-FDMA has a couple of constraints in association with resource allocation (RA) which are exclusivity and adjacency constraints according to which a subchannel can be assigned to one users at a time and only adjacent multiple subchannels can be assigned to a user, respectively [10].

A. RELATED WORK

Different RA problems for heterogeneous networks (HetNets) and two-tier C-RANs have been studied in the literature [11-25]. Kuang *et al.* [11] proposed joint BS association, subchannel assignment (SA), beamforming and power allocation (PA) technique in OFDMA based HetNets. Awais *et al.* [12] formulated a joint RRH-association and RA problem for maximizing the throughput and network utilization under practical network limitations. Feng *et al.* [13] presented a public safety network architecture based on C-RAN and developed a RA algorithm with the objective of throughput maximization. A joint RA and admission control scheme for an OFDMA-based Heterogeneous C-RAN architecture is presented in [14]. While in [15], a new data rate aware on-demand dynamic spectrum allocation algorithm is presented, considering interference-mitigation in C-RAN.

Zhang *et al.* [16] have presented an exhaustive overview on the widespread research works 4G and 5G systems, such as OFDMA, multiple-input multiple-output (MIMO), and HetNets and classified them based on the fundamental green-tradeoffs. They also discussed the possible challenges and effects of fundamental green-tradeoffs, to reveal the energy-efficient research for future wireless networks. Feng *et al.* [17] presented an overview of the up-to-date research progress on green 5G systems and energy-harvesting for communication. Shi *et al.* [18], studied the joint RRH-selection and transmit-power minimization via beamforming subject to guaranteeing the user data-rate requirements while for the same objective of energy efficiency maximization, Huang *et al.* [19] and Yoon and Cho [20] presented power allocation schemes for MIMO-based C-RANs and Heterogeneous C-RAN, respectively. Luo *et al.* [21], considered a similar problem as in [18] and developed a joint UL and downlink (DL) user-association and beamforming algorithms. However, [18] and [21] considered the ideal fronthaul links in single channel single-tier networks. Subchannel assignment is further investigated in [18] jointly with PA and beamforming to enhance the C-RANs energy efficiency. In [22], a joint RRH activation, RA and beamforming algorithm is presented for transmit-power minimization C-RANs. User association along with RRH activation is further considered in [23] for the same objective of [18], while in [24], the authors investigated an energy efficient SA and PA algorithm in Heterogeneous C-RAN.

B. CONTRIBUTION

To the best of our knowledge, joint optimization of RRH-association, SA and PA sum-rate maximization in the UL of SC-FDMA based multi-tier C-RANs is not available in the literature. All the works in [11]–[24] on resource allocation in two-tier HetNets and C-RANs considered OFDMA as multiple access technique. However, due to the adjacency and exclusivity constraints of SC-FDMA, none of these works can be utilized for the UL of SC-FDMA-based multi-tier C-RAN. More specifically, [11]–[15] studied joint optimization of different resources (e.g., power and subchannel allocation) for the objective of sum-rate maximization while [16]–[24] targeted energy efficiency as objective. In this paper, we present an iterative algorithm which jointly perform RRH-association, SA and PA in the UL of SC-FDMA based multi-tier C-RAN. The objective of this work is network sum-rate maximization subject to maximum power budget, subchannel exclusivity and subchannel adjacency constraints. The joint optimization problem is a mixed-integer nonlinear problem (MINLP) which is prohibitively difficult to solve, and thus, the optimal solution is difficult for reasonably sized network. Therefore, an iterative-algorithm is derived through converting the initial MINLP into a two-step optimization framework. In the first step, SA and PA are carried out for the fixed RRH-association while in the second step, RRH-association is updated.

The remaining of this paper is ordered as follows. In Section II, the system model and problem formulation are presented. In Section III, a two-step algorithm is proposed to solve the problem formulated in Section II while Section IV contains the simulation results and discussions. The paper is concluded in Section V.

II. SYSTEM MODEL AND PROBLEM FORMULATION

The following two subsections contain the system model and joint RRH-association, SA and PA problem, respectively.

A. SYSTEM MODEL

We consider the UL of a SC-FDMA based multi-tier 5G C-RAN which contains total of 3 communication tiers as illustrated in Fig. 1. Each tier is served by a particular RRH: for example, tier 1 is served by macrocell-RRH, tier 2 is served by picocell-RRHs and tier 3 is served by femtocell-RRHs. Furthermore, there are total of M RRHs (macrocell-RRH + picocell-RRHs + femtocell-RRHs) where $(M-1)/2$ femtocell-RRHs and the same number of picocell-RRHs are underlayed in the macrocell. Our presented multi-tier C-RAN consists of a BBU-pool connected to an MBS-RRH

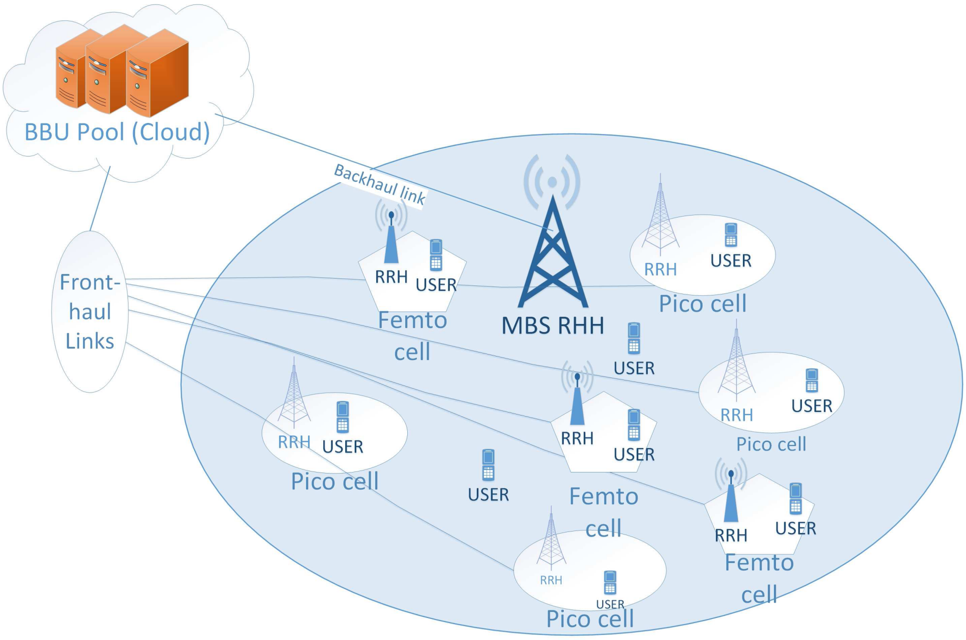

FIGURE 1. Illustration of Multi-tier C-RAN.

through backhaul link and small cell RRHs (i.e., femtocells and picocells) connected to the BBU through fronthaul links. In the presented architecture, transmitting control signals to C-RAN and data transmission are the duties of MBS-RRH and small cell RRHs, respectively. Moreover, SC-FDMA is considered as UL multiple access technique in our presented multi-tier C-RAN.

Furthermore, it is supposed that there are total K randomly deployed users. The available transmission bandwidth is subdivided into N subchannels. All the N subchannels are reused at each RRH due to which the users of each RRH causes interference to the users of all the other RRHs in the system. On the other hand, the users associated to each individual RRH will share the N subchannels orthogonally. That is, at each RRH, a subchannel can be assigned to one of its associated users at a time thereby fulfilling the subchannel exclusivity constraint of SC-FDMA [7]. The subchannel adjacency constraint of SC-FDMA [7] should also be fulfilled, whereby only adjacent multiple subchannels can be assigned to a user. In addition, it is supposed that each user is served by a single RRH.

Each user can be assigned multiple subchannels as long as the power of transmission is constrained as

$$\sum_{n \,\epsilon\, N_k} p_{k,n} \;\leq\; p_k^{max}, \;\; \forall\, k \tag{1}$$

where $p_{k,n}$ is the transmit-power of *kth* user on *nth* subchannel and p_k^{max} represents the maximum per user transmit power.

The *SINR* of *kth* user on *nth* subchannel is given in the following equation.

$$\gamma_{k,n}^{m} = \frac{p_{k,n}\, |h_{k,n}^{m}|^2}{\sigma^2 \,+\, I_{k,n}^{m}} \tag{2}$$

TABLE 1. List of symbols.

Symbols	Description
M	Total RRHs
N	Total subchannels
K	Total users
$p_{k,n}$	Transmit-power of kth user on nth sub-channel
p_k^{max}	Maximum per user transmit power
$\alpha_{k,m}$	User association of user k with RRH m
$\gamma_{k,n}^m$	SNIR of user k on subchannel n to RRH m
$\|h_{k,n}^m\|^2$	Channel gain of user k on subchannel n to RRH m
$I_{k,n}^m$	Interference on nth sub-channel of kth user to RRH m
$p_{l,n}$	Transmit-power of the lth user on nth sub-channel
$\|h_{l,n}^m\|^2$	Channel gains of the lth user on nth sub-channel to RRH m
σ^2	Noise
$R_{k,n}^m$	The achievable data-rate of user k on sub-channel n to RRH m

where

$$I_{k,n}^{m} \;=\; \sum_{l \,\neq\, k} p_{l,n}\, |h_{l,n}^{m}|^2 \tag{3}$$

$|h_{k,n}^m|^2$ is the channel gain of *kth* user on *nth* subchannel to RRH m, σ^2 represents noise and $I_{k,n}^m$ is the interference on *nth* sub-channel of *kth* user to RRH m. $p_{l,n}$ is the transmit power of the *lth* user on *nth* subchannel while $|h_{l,n}^m|^2$ shows the channel gain of the *lth* user on *nth* sub-channel to RRH m.

The achievable date-rate of user k in bits/sec is given as follows

$$R_k^m \;=\; W\, |N_k^m| \log_2 \left(1 + \frac{1}{|N_k^m|} \sum_{n \,\epsilon\, N_k} (\gamma_{k,n}^m) \right) \tag{4}$$

Where N_k^m with cardinality $|N_k^m|$ is the subchannels set assigned to the *kth* user connected to RRH m.

B. THE JOINT RRH-ASSOCIATION, SUBCHANNEL ASSIGNMENT AND POWER ALLOCATION PROBLEM

Based on the assumptions in system model, the joint RRH-association, SA and the PA problem is formulated in this section. The objective of this joint optimization problem is sum-rate maximization subject to transmit-power budget, subchannel exclusivity and adjacency constraints.

We introduce a RRH-association matrix as given by

$$\alpha_{k,m} = \begin{cases} 1, & \text{if user } k \text{ is associated with RRH } m \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

and formulate our joint optimization problem as follows:

$$\max \sum_{m=1}^{M} \sum_{k=1}^{K} \alpha_{k,m} \ R_k^m \tag{6}$$

$$s.t. \sum_{n \,\epsilon\, N_k} p_{k,n} \le p_k^{max}, \ \forall k, \ p_{k,n} \ge 0, \ \forall k, n \tag{7}$$

$$\sum_{m=1}^{M} \alpha_{k,m} = 1, \ \forall k, \ \ \alpha_{k,m} \,\epsilon\, \{0, 1\}, \ \forall k, m \tag{8}$$

$$N_k^m \bigcap N_j^m = \emptyset, \ \forall k \neq j, \ \forall m \tag{9}$$

$$\left\{ n \cap \left(\bigcup_{j=1, j\neq k}^{k} N_j^m \right) = \emptyset \middle| \ n \epsilon \left\{ n_1, n_1+1, \ldots, n_2-1, n_2 \right\} \right\}, \ \forall k, \ m \tag{10}$$

where $n_1 = min(N_k^m)$, $n_2 = max(N_k^m)$.

Equation 6 represents the objective function which is sum-rate maximization of the system. Equation 7 represents the maximum per user transmit power constraint while Equation 8 represents the RRH-association constraint which tells that a user can be served by a single RRH. The constraint in Equation 9 reflects the fact that each subchannel can be assigned to one user at a time. The constraint in Equation 10 ensures that all the subchannels in set N_k^m are contiguous.

III. THE PROPOSED TWO-STEP ALGORITHM

The joint RRH-association, SA and PA problem in Equations 6-10 is MINLP. Even for a given RRH-association and power allocation, the optimal subchannels assigning among the users alone is prohibitively difficult. This difficulty mainly arises due to the subchannels exclusivity and adjacency constraints given in Equations (9) and (10) which results in extremely large search space. Consequently, the exhaustive search is not practical and the solution of the problem in its current form is prohibitively complex. Therefore, to solve the joint optimization problem in Equations 5-9, a two steps iterative algorithm is proposed which jointly optimizes subchannel assignment, power allocation and RRH-association. The proposed two steps algorithm is discussed in the following subsections.

A. SUBCHANNEL ASSIGNMENT AND POWER ALLOCATION

SA and PA are carried out in this step. We considered the initial RRH-association $\boldsymbol{\alpha}^0$ such that $\boldsymbol{\alpha}^0 = \{\alpha_1^0, \alpha_2^0, \ldots, \alpha_K^0, \}$ and initial PA $\boldsymbol{p}^0$ such that $\boldsymbol{p}^0 = p_{k,n}^0, \ \forall k, \ \forall n$. For initialization, we used uniform PA and path-loss based association where $\forall k, \forall n : p_{k,n}^0 = (p_k^{max}/N)$, and $\forall k : \alpha_{k,\bar{m}}^0 = 1$ for $\bar{m} = \arg min \ d_{k,m}$; $\alpha_{k,m}^0 = 0, \ \forall m \neq \bar{m}$. $d_{k,m}$ represents the distance between user k and RRH m. For this step the problem 6-10 can be rewritten as

$$\max \sum_{m=1}^{M} \sum_{k=1}^{K} \alpha_{k,m} \ R_k^m \tag{11}$$

$$N_k^m \bigcap N_j^m = \emptyset, \ \forall k \neq j, \ \forall m \tag{12}$$

$$\left\{ n \cap \left(\bigcup_{j=1, j\neq k}^{k} N_j^m \right) = \emptyset \middle| \ n \epsilon \left\{ n_1, n_1+1, \ldots, n_2-1, n_2 \right\} \right\}, \ \forall k, \ m \tag{13}$$

At the beginning of *ith* iteration where $i \ge 1$, by solving this problem for given $\boldsymbol{\alpha} = \boldsymbol{\alpha^i}$ and $\boldsymbol{p} = \boldsymbol{p^i}$, subchannels are assigned to each user which gives N_k^m. For subchannel assignment, we proposed two algorithms namely individual subchannel allocation (ISA) algorithm and subchannels block allocation (SBA) algorithm which are discussed in the following subsections 1 and 2 while power allocation is discussed in subsection 3.

1) INDIVIDUAL SUBCHANNEL ALLOCATION ALGORITHM

In ISA algorithm, the achievable rate of every user on each subchannel is calculated iteratively and then the subchannel is assigned to the user having highest achieved rate on that subchannel in each iteration. After assigning a subchannel to a user in the above mentioned way, the achievable rate on the immediate next subchannel is calculated for every user. If the user having highest achieved rate on this subchannel is the same to which the immediate previous subchannel has been assigned, then this subchannel is also assigned to the same user. Otherwise, the previously assigned user will not be considered for the remaining subchannels due to the adjacency constraint of SC-FDMA. This way, all the subchannels are assigned to the users. The step wise operation of the ISA algorithm is given in Algorithm 1.

where $\widetilde{M}$ is the set of RRHs, $\widetilde{N^m}$ is the subchannel set available at RRH m and $\widetilde{K}$ is the set of total users. Furthermore, N_k^m and $N_k^{m,f}$ shows the sub-channels set currently assigned to user k connected to RRH m and the feasible set of subchannels for user k connected to RRH m, respectively.

Algorithm 1 ISA Algorithm

```
Step 1: Initialization $M$; $N$; $K$; $\widetilde{M} = \{1, ...., M\}$; $\widetilde{N^m} = \{1, ...., N\}$; $\widetilde{K} = \{1, ...., K\}$; $N_k^m = \phi, \forall\, k \in \widetilde{K}, \forall\, m \in \widetilde{M}$; $N_k^{m,f} = \widetilde{N^m}, \forall\, k \in \widetilde{K}, \forall\, m \in \widetilde{M}$
for $m = 1 : M$
    Step 2: Assign a subchannel $n$ to a user $k$ which achieves highest data-rate on it. This gives a user subchannel pair $(k^*, n^*)$.
    Step 3: Update $N_{k^*}^m$ and $N_{k^*}^{m,f}$.
    Step 4: Satisfying the subchannel exclusivity and adjacency constraints, repeat step 2 and 3, respectively, until $\widetilde{N^m}$ goes empty.
end
```

2) SUBCHANNELS BLOCK ALLOCATION ALGORITHM

In SBA algorithm, the available subchannels are divided into small groups containing equal number of contiguous subchannels in such a way that the number of groups is equal to the number of associated users. Unlike the ISA algorithm, in SBA algorithm, the achievable rate of every user is calculated on each group of subchannels and then the group of subchannels is assigned to the user with highest achieved sum-rate on this group. The user which has been assigned the subchannel group, will not be considered for assigning the remaining subchannels groups. The remaining groups are assigned to the remaining users in the same way. The step wise operation of the SBA algorithm is given in Algorithm 2.

Algorithm 2 SBA Algorithm

```
Step 1: Initialization: $M$; $G$; $K$; $\widetilde{M} = \{1, ...., M\}$; $\widetilde{G^m} = \{1, ...., G\}$; $\widetilde{K} = \{1, ...., K\}$; $G_k^m = \phi, \forall\, k \in \widetilde{K}, \forall\, m \in \widetilde{M}$; $G_k^{m,f} = \widetilde{G^m}, \forall\, k \in \widetilde{K}, \forall\, m \in \widetilde{M}$
for $m = 1 : M$
    Step 2: Assign a subchannels-group $g$ is to a user $k$ which achieves highest data-rate on it. This gives a user subchannels-group pair $(k^*, g^*)$.
    Step 3: Select a $g \neq g^*$ and assigned it to a $k \neq k^*$ based on the same criteria mentioned in Step 2.
    Step 4: Repeat Step 3 until $\widetilde{G^m}$ goes empty.
end
```

where $\widetilde{G^m}$ is the available set of subchannels-groups. G_k^m and $G_k^{m,f}$ shows the subchannels group currently assigned to user k connected to RRH m and the feasible set of subchannels group for user k connected to RRH m, respectively.

3) POWER ALLOCATION ALGORITHM

After getting N_k^m by performing SA and for given $\boldsymbol{\alpha} = \boldsymbol{\alpha}^i$, power is allocated across all subchannels of each user using a) Interior Point Algorithm (IPA) and b) Equal Power Distribution (EPD). IPA (also known as barrier algorithm) is used to solve linear and nonlinear optimization problems. There are three main reasons which make the IPA an attractive method: (i) ease of managing inequality constraints by logarithmic barrier functions, (ii) relaxation in the requirement of strictly feasible initial guess and (iii) fast convergence [25]. The IPA involves four phases to get optimality conditions. First, the inequality constraints are transformed into equality constraints by the addition of slack-variables to the former. Second, non-negativity situations are implicitly tackled by adding them to the objective function as logarithmic barrier terms. Third, the optimization problem with equality constraints is transformed into unconstrained optimization problem. Fourth, the perturbed Karush-Kuhn Tucker first order optimality conditions are solved through the Newton method. For further details, the work in [26] can be referred. While according to EPD, the maximum transmit-power of a use k is equally distributed among all the assigned subchannels of that user while IPA is used to provide optimal PA. In this paper, we consider total of K users and N subchannels. The set of subchannels assigned to user k associated to RHH m is N_k^m. Furthermore, the maximum transmit-power of a user is set to p_k^{max} then according to EPD, power can be allocated as below

$$p_{k,n} = p_k^{max}/|N_k^m|, \quad \forall\, k, n, m \tag{14}$$

As a special case using IPA, if a user allocates zero power to a subchannel, then, to include that subchannel in the next iteration, we will assign a small power ρ to that subchannel such that $0 < \rho << 1\, watt$.

After performing SA and PA, we consider the obtained solution as p^{i+1}.

B. RRH-ASSOCIATION

The second step of the proposed algorithm is concerned with RRH-association optimization. In this step, we find the optimal RRH-association ($\boldsymbol{\alpha}$) for problem 6-10 with p^{i+1}. After obtaining sub-channel allocation N_k^m and power allocation p^{i+1} in the first step, the RRH-association problem can be rewritten as

$$\max \sum_{m=1}^{M} \sum_{k=1}^{K} \alpha_{k,m}\ R_k^m \tag{15}$$

$$s.t. \sum_{m=1}^{M} \alpha_{k,m} = 1,\ \forall\, k,\ \alpha_{k,m} \in (0, 1),\ \forall\, k, m \tag{16}$$

The above problem can be solved by setting all $\alpha_{k,m}$ to zeros, except that $\alpha_{k,\bar{\bar{m}}=1}$ where $\bar{\bar{m}}$ is given in the following equation.

$$\bar{\bar{m}} = \arg\ \max(R_k^m) \tag{17}$$

The solution is carried out using integer relaxation method. For each user k, the proposed algorithm associate the user with RRH which is most beneficial for this user. We represent this solution by α^{i+1} and then next iteration begins. The flow chart of the presented two-step algorithm is given in Fig. 2.

The proposed techniques will converge after a few iterations. In our numerical simulation, both the techniques take only 3 iterations to converge.

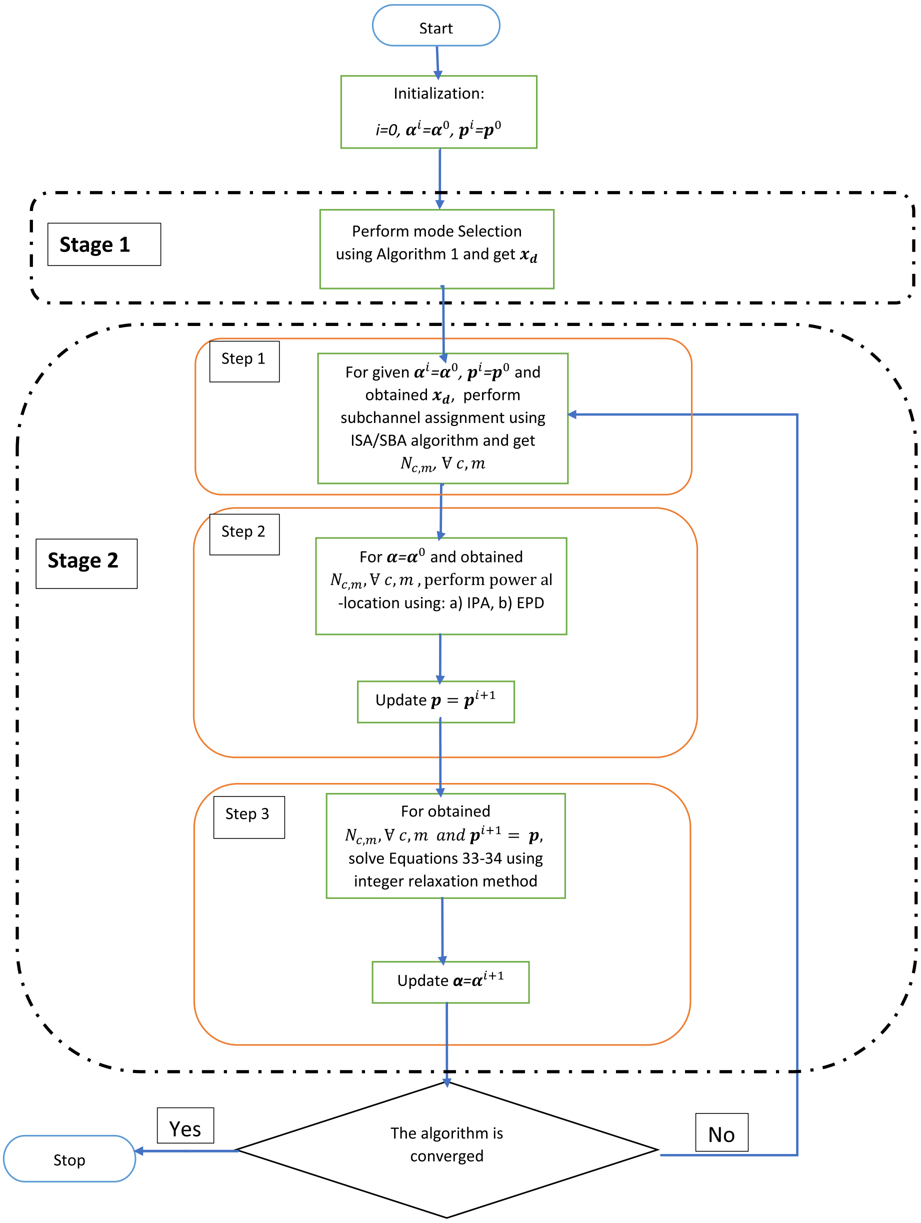

FIGURE 2. Flow chart of the proposed algorithm.

IV. NUMERICAL RESULTS

In this section, the performance of our presented algorithms has been evaluated. We consider an underlay multi-tier C-RAN in uplink which contains a macrocell-RRH having cell radius of r meters, two femtocell-RRHs and two picocell-RRHs. The RRHs are placed in such a manner that the macrocell-RRH is positioned at the center of the cell. Moreover, two picocell-RRHs (i.e, P1-RRH and P2-RRH) are deployed at 0° and 180°, respectively, while two femtocell-RRHs (i.e, F1-RRH and F2-RRH) are deployed at 90° and 270°, respectively, from positive X-axis on a circle of radius $r/2$ meters as shown in the Fig. 3. Total system bandwidth is 9 MHz divided into N orthogonal sub-channels and there are K randomly deployed users. The band width of each subchannel is 200 KHz. We assume a frequency selective rayleigh-fading channel having a standard deviation of 8 dB while the channel gain is consisting of a large scale path-loss part and a small scale path-loss part. The power spectral density of noise is taken as -174 dBm/Hz while cost-Hata Model [27] is used for path-losses computation. Different parameters and their values/types used in simulations are listed in the table II.

We compare the performance of our presented ISA based sub-optimal power & RRH association (ISA-SOPARA) and SBA based sub-optimal power & RRH association (SBA-SOPARA) algorithms with optimal algorithm and

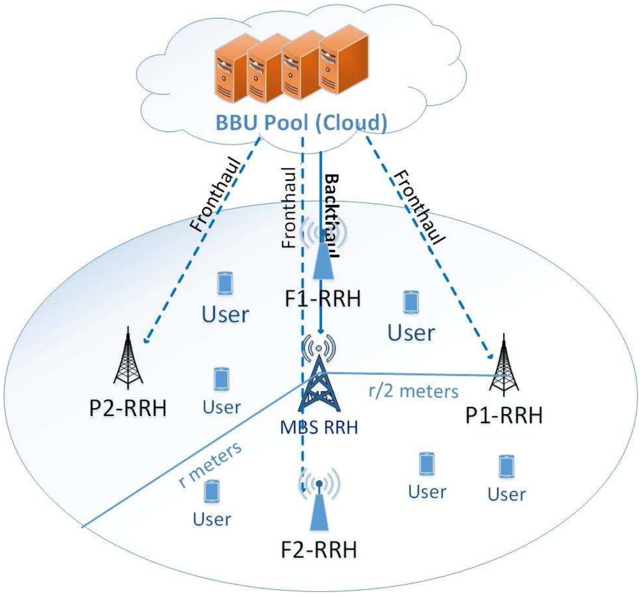

FIGURE 3. Simulations Scenario.

TABLE 2. Simulations parameters.

Parameter	Values/types
Total number of RRHs	5 (one MBS RRH, two femtoocell RRH and two picocell RRH)
System bandwidth	9 MHz
Bandwidth per subchannel	200 KHz
Path-loss model	Cost HATA model
Power spectral density of noise	-174 dBm/Hz
Channel type	Frequency selective rayleigh fading channel
Standard deviation of shadow fading	8 dB
Simulator	Matlab

Equal Power and Equal Subchannel allocation (EPES) algorithm. For optimality, we use IPA and integer relaxation method. Integer relaxation method is use for optimal RRH-association while IPA is used for optimal PA. In the EPES algorithm, each user is assigned an equal set of contiguous sub channels while the maximum transmit-power of each user is equally divided among the contiguous subchannels assigned to it.

To evaluate the sum-rate performance of the presented algorithms, we plot the sum-rate verses different transmit power values for fixed number of sub-channels and users in Fig. 4. This figure shows that our presented ISA-SOPARA and SBA-SOPARA algorithms result in considerably higher sum-rate than the EPES algorithm for the entire range of transmit powers values. As for as, the performance comparison of our two presented algorithms is concerned, the SBA-SOPARA algorithm shows better performance than the ISA-SOPARA algorithm and it is close to the optimal algorithm in terms of achieved sum-rate. This figure illustrates that initially when the transmit power is 0.2 watt, the sum-rate of the optimal algorithm, SBA-SOPARA algorithm, ISA-SOPARA algorithm and EPES algorithm are 31 Mb/sec, 26 Mb/sec and 17 Mb/sec, respectively. The sum-rate gradually increases with increase in transmit power and reach up to 40 Mb/sec, 32 Mb/sec, 28 Mb/sec and 25.2 Mb/sec, respectively, for all four algorithms in the above mentioned order. This is because the link's rate is in direct relation to *SINR*, and *SINR* is, in turn, in direct relation to transmit power.

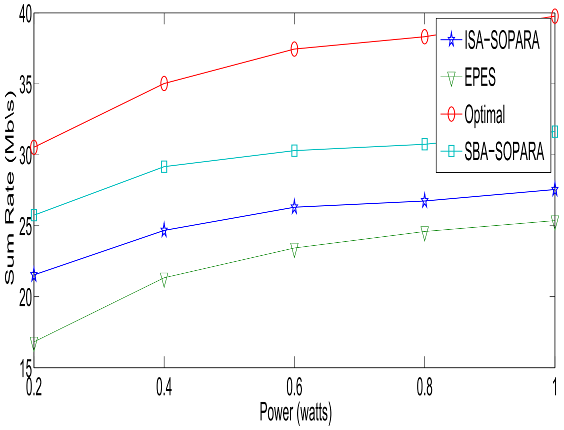

FIGURE 4. The effect of transmit-power on network sum-rate.

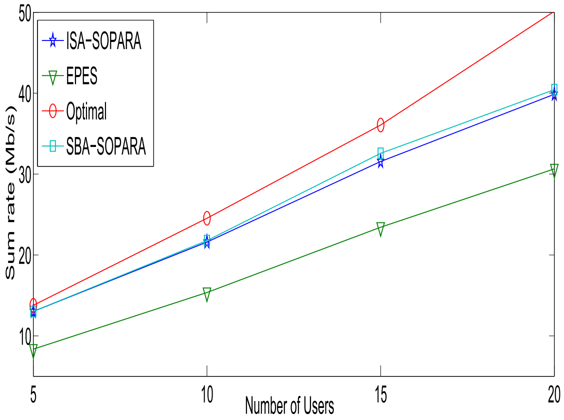

FIGURE 5. Network sum-rate verses various number of users for $N = 25$ and $p_u^{max} = 0.4$ *watts*.

To illustrate the impact of number of associated users on sum-rate performance of the presented algorithms, we plot sum-rate against different number of users in Fig. 5 while keeping N and p_u^{max} fixed. It is clear from the figure that our presented algorithms (ISA-SOPARA and SBA-SOPARA) shows better performance than the EPES algorithm while they are closed to the optimal algorithm in term of sum-rate maximization. Among our presented two algorithms, SBA-SOPARA algorithm performs better than the ISA-SOPARA algorithm.

In Fig. 6, we plot the sum-rate verses different number of subchannels for fixed K and p_u^{max}. The Fig. 6 clearly shows that our presented ISA-SOPARA algorithm and

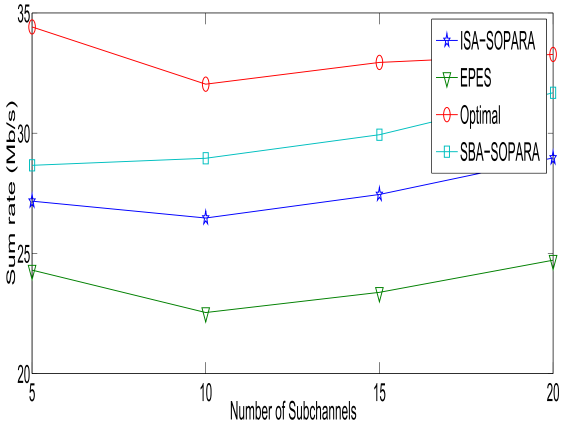

FIGURE 6. Network sum-rate verses various number of subchannels for $K = 5$ and $p_u^{max} = 0.4$ *watts*.

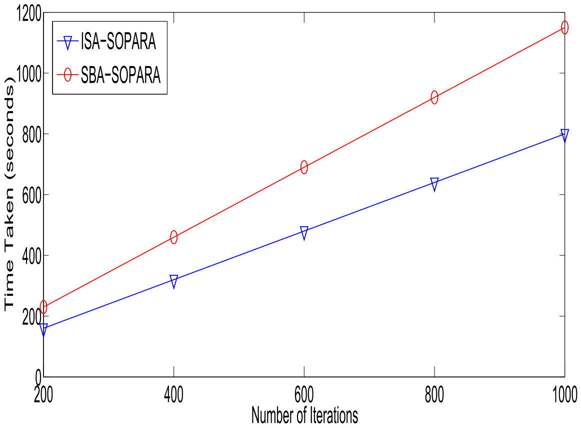

FIGURE 8. Computational complexity comparison of the proposed ISA-SOPARA and SBA-SOPARA algorithms for N = 25, K = 15 and $P_u^{max} = 0.4$ *watts*.

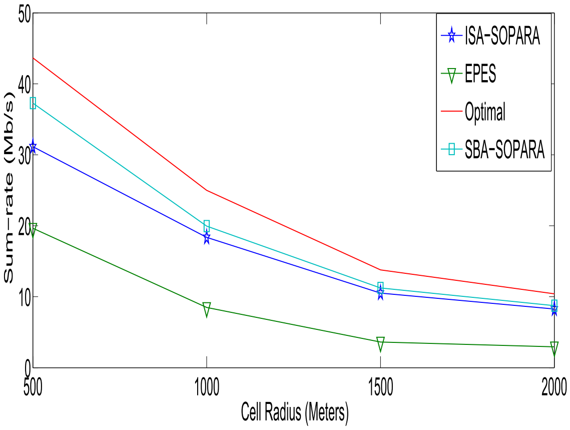

FIGURE 7. The effect of cell size on network sum-rate.

SBA-SOPARA algorithm result in higher sum-rate the EPES algorithm while among the two presented algorithms, SBA-SOPARA algorithm outperforms ISA-SOPARA algorithm.

The Fig. 7 shows the effect of cell size on network sum-rate where, the behavior of network sum-rate against 500 m, 1000 m, 1500 m and 2000 m cell radii is investigated for K, N and p_u^{max}. The network sum-rate performance of the all four algorithms, (i.e., optimal algorithm, SBA-SOPARA algorithm, ISA-SOPARA algorithm and EPES algorithm) is in the same order as it is in Figure 3, 4 and 5. The figure shows that for 500 m cell radius, optimal algorithm, SBA-SOPARA algorithm, ISA-SOPARA algorithm and EPES algorithm result in 28 Mb/sec, 38 Mb/sec, 47 Mb/sec and 62 Mb/sec, respectively, which gradually reduce to 31 Mb/sec, 26 Mb/sec, 20 Mb/sec and 11 Mb/sec, respectively, for 2000 m cell radius. This is because, the farther a user is from its RRH, the more the signal-strength drops and the lower the data rates that it can reliably achieve.

Finally, both the proposed ISA-SOPARA and SBA-SOPARA algorithms are compared in terms of computational complexity in Fig. 8. To this end, the algorithms are run for various number of iterations for which the computational time has been found. The figure reveals that the SBA-SOPARA algorithm is 34% more efficient than the ISA-SOPARA algorithm in terms of computational complexity.

V. CONCLUSION

In this paper, we considered a SC-FDMA based multi-tier C-RAN and presented an iterative algorithm performing the joint optimization of RRH-association, SA and PA for sum-rate maximization in UL. The presented iterative algorithm solves our joint optimization problem in two steps. SA and PA are performed in the first step while the second step of the presented algorithm is concerned with RRH-association. We compared the performance of our presented ISA-SOPARA and SBA-SOPARA algorithms with optimal and EPES algorithms and the simulation results show that our presented algorithms provide better performance than EPES algorithm and are close in performance to optimal algorithm. While among the presented ISA-SOPARA and SBA-SOPARA algorithms, the later performed better.

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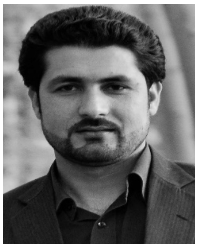

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