Energy-Efficiency for MISO-OFDMA Based User-Relay Assisted Cellular Networks

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Abstract—**The concept of improving energy-efficiency (EE) without sacrificing the service quality has become important nowadays. The combination of orthogonal frequency-division multiple-access (OFDMA) multi-antenna transmission technology and relaying is one of the key technologies to deliver the promise of reliable and high-data-rate coverage in the most cost-effective manner. In this paper, EE is studied for the downlink multiple-input single-output (MISO)-OFDMA based user-relay assisted cellular networks. EE maximization is formulated for decode and forward (DF) relaying scheme with the consideration of both transmit and circuit power consumption as well as the data rate requirements for the mobile users. The quality of-service (QoS)-constrained EE maximization, which is defined for multi-carrier, multi-user, multi-relay and multi-antenna networks, is a non-convex and combinatorial problem so it is hard to tackle. To solve this difficult problem, a radio resource management (RRM) algorithm that solves the subcarrier allocation, mode selection and power allocation separately is proposed. The efficiency of the proposed algorithm is demonstrated by numerical results for different system parameters.**

Index Terms— **Decode and forward relays, energy-efficiency, multi-antenna transmission technology, orthogonal frequency-division multiple-access, user-relays.**

I. INTRODUCTION

In recent years, both industry and academia have focused on energy-efficient communications because of the increasing cost for energy consumption, ecological, and environmental reasons and the short battery life of the mobile devices. Energy efficiency (EE) metric, which enlarges the system capacity and meanwhile reduces the total power consumption, has been adopted as one of the new obligatory performance metrics for 5G systems besides spectral-efficiency (SE) [1].

Next generation wireless networks are expected to provide high capacity and coverage for data applications. Well known key technologies, including orthogonal frequency division multiple access (OFDMA), relaying and multi-antenna transmission technology, are used to reach these targets. Robustness against frequency-selective fading, high SE and flexible resource allocation make OFDMA a very popular transmission technology for high data rate communication systems. Capacity gain can be provided by using multi-

antenna transmission technologies, such as multiple-input multiple-output (MIMO) or multiple-input single-output (MISO), without increasing the bandwidth or transmit power in rich scattering environments. Moreover, diversity gain is achieved to combat signal fading compared with classical single-input single-output (SISO) systems. Relay assisted communication is also a powerful technology that provides reliable transmission by increasing the throughput, expanding the coverage and mitigating the fading. In relaying, path-loss and shadowing effects become less dominant so the EE of the communication systems can be improved due to the low power communication. The relay nodes can be fixed or mobile [2][3]. Using fixed relay nodes leads to high infrastructure costs and high operational and maintenance costs for the mobile operators. Mobile relay nodes have the advantage that they can increase the system performance without requiring any additional infrastructure cost. Thus, user relaying is a good candidate for the 5G wireless systems [4][5]. These technologies can be combined in order to construct a multi-carrier, multi-user, multi-relay and multi-antenna network to deliver the promise of reliable and high data-rate coverage in the most cost-effective manner.

Efficient allocation of resources (frequency, power) plays a significant role in achieving EE in wireless cellular networks. Recently, much effort has been spent in developing energy-efficient radio resource management (RRM) schemes. Many works have investigated the EE maximization problem for classical SISO-OFDMA networks with fixed relays [6]-[8] and user-relays [9]-[12]. In [9], decode and forward (DF) user relays were used and EE problem was formed by using individual user rate constraints for an uplink scenario. Although the optimization problems that aim to maximize data rate or to minimize the power are not effective for EE purpose, [9] used power minimization for green communication to simplify the problem by eliminating the fractional form of the objective function. In [10], average EE maximization problem was defined under the quality of service (QoS) constraints of the users for OFDMA based user-relay aided cellular networks. The relay selection, resource allocation and power allocation were solved jointly for amplify and forward (AF) relaying system. In [11], the authors defined EE maximization problem by using discrete modulation levels in order to make the problem more practical and presented a RRM algorithm for their defined optimization problem. In [12], the EE maximization problem was defined for DF user relaying scheme by considering the QoS requirements of the users and two-step practical solution was presented. EE maximization problem in which system capacity is enlarged and system energy consumption is reduced at the same time also transferred to the multi-antenna transmission scheme [13]-

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[17]. Although, increasing antenna elements provides advantages on resource allocation problem because of the spatial multiplexing, the increasing number of radio frequency (RF) chain (including mixers, filters, digital-to-analog converters, etc.) also increase the energy consumption. Thus, EE maximization problem is also very important problem for multi-antenna transmission scheme. In [13], the EE maximization problem was defined for MISO downlink cellular networks and optimal beamformer design was studied. In [14], EE problem was applied for multi-cell MISO downlink cellular networks and EE fairness between the base stations (BSs) was set as the target of the study. In [15], EE problem was formulated for MISO-Orthogonal Frequency Division Multiplexing (OFDM) systems and presented a suboptimal solution. The inter-user interference problem on subcarriers was ignored in [15] since one user was supported for each subcarrier. In [16], joint subcarrier allocation and precoder design was presented to maximize EE for MIMO-OFDMA downlink and also only one user was allocated for each subcarrier to eliminate interference among users. In [17], the authors integrated relaying to MIMO-OFDMA downlink cellular networks and studied on the SE and EE maximization trade-off. The EE problem for multiple antenna networks was studied by ignoring relays in [13]-[16], and by using fixed-relays in [17].

The EE maximization problem for user-relay assisted multi-antenna OFDMA networks has not been addressed in the literature, so we focus on that issue in this paper. A summary of the main contributions of this paper can be listed as follows:

- EE maximization problem with minimum data rate requirement of the users is defined for downlink MISO-OFDMA based user-relay assisted cellular networks. A widely used metric defined as the ratio of total data rate to total power consumption is used to measure the system EE. This metric is more effective than power minimization [9] for green communication.

- The formulated problem is a mixed combinatorial and non-convex problem and is in the class of mixed-integer non-linear programming (MINLP) problem. The EE metric is also a fractional and nonlinear function, which complicates the problem further. Different algorithms, such as branch-and-bound, outer approximation and generalized Bender's decomposition, can be used to solve MINLP type problems [18]. However, when the size of the problem is large, as in our multi-carrier, multi-user, multi-relay and multi-antenna scenario, they are not suitable because of the high complexity. In the literature, to make the original optimization problem tractable, different strategies are used. For example, the problem was solved jointly by using convex relaxation in [6][10][19], but was decomposed into parts in [7][20] to solve integer and continuous variables separately. However, the complexity of the joint convex relaxation based solutions are still high. Thus, we decompose the problem into parts and propose a two-step solution to

reduce the complexity and to make the problem more manageable. In the first step, a heuristic algorithm is proposed for mode selection and subchannel allocation. In the second step, Dinkelbach method [21], which is widely used to solve fractional problems, is used to perform the energy-efficient power allocation by using the outputs of the first step.

- We present simulation results to evaluate the effectiveness of the proposed solution. We discuss the effect of many parameters such as the number of transmitter antennas, dynamic power consumption, the number of users, minimum required data rate and cell radius. We also reveal the trade-off between EE and SE for given system model and discuss it in detail. Besides, we compare the proposed scheme with the exhaustive search scheme and we observe that the proposed scheme decreased the computational complexity meaningfully by sacrificing the system EE performance slightly.
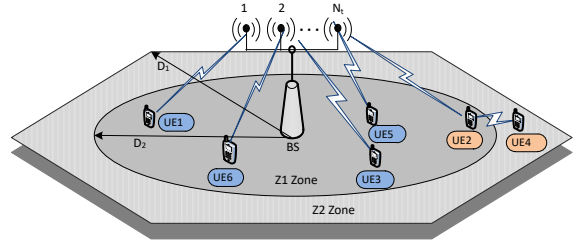

Fig. 1. MISO-OFDMA cellular network model with user relays.

II. SYSTEM MODEL AND PROBLEM STATEMENT

A. System Model

In this paper, we concentrate on the downlink MISO-OFDMA based user-relay assisted single cell network model as in Figure 1. The BS has N_t antennas and K mobile users also called User-Equipments (UEs) have one antenna each. The cellular area around the BS is partitioned into two zones as $Z1$ and $Z2$. It is assumed that the BS transmits data directly to the UEs located in $Z1$, represented by $\mathbb{A} = \{1, 2, \ldots, a, \ldots A\}$, due to good channel conditions. However, it transmits data to the UEs located in $Z2$, represented by $\mathbb{B} = \{A + 1, A + 2, \ldots, b, \ldots A + B\}$, with the help of user-relays because of the heavy blockage and long transmission range. The UEs in $Z1$ are not only mobile users but also user-relays of the $Z2$ users. The data transmission is performed in two equal time slots and the available bandwidth of the system BW, is divided into N subchannels, each of which consists of a set of adjacent OFDM subcarriers as shown in Figure 2. The data transmission can be completed in one time slot for UEs in $Z1$ but it takes two time slots for $Z2$ users, who need help from user-relays. In the first time slot, the BS transmits data to the $Z1$ users, that receive data for themselves as direct users or receive data for UEs in $Z2$ as user-relays. In the second time slot, BS goes on sending data to the direct users but user-relays start to forward data received in the first time slot to the $Z2$ users by using DF relaying protocol. The same or different

subchannels can be used for reception and transmission of data by relay nodes in two time slots. Same subchannel policy simplifies the problem and decreases the computational complexity. Thus, this policy is preferred for our complex environment that considers multiple users, multiple antennas, multiple relays and multiple subchannels. We also assume that all required channel gains between any nodes are available at the BS [6][7][10]-[17].
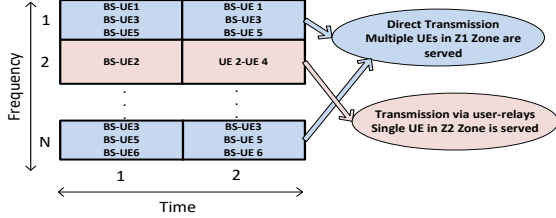

Fig. 2. Data transmission process in two-time slots

B. Total Data Rate and Power Consumption Model

In this study, the BS has multiple transmit antennas as shown in Figure 1, so multiple users can be served on each subchannel simultenaously. If the number of users is more than the number of transmit antennas, user selection is required since the number of maximum supportable users at each time and frequency slot can not be more than the number of transmit antennas. We assume that on each subchannel, BS can transmit to either $Z1$ users directly or $Z2$ users via user-relays. In the former, more than one users can be served since the communication channel between the BS and any UE is a MISO channel. In the latter, although the channel between the BS and user-relay is MISO in time slot one, there will be a SISO channel in the second time slot between user-relay and UE. Thus, only one $Z2$ user can be served for each subchannel. This case is illustrated in Figure 2 to make the transmission process clearer.

The selected user set on subchannel n can be assumed as $\mathcal{Z}_n^q = [z_1, z_2, \ldots, z_q]$. Here index q represents the supported number of users and its value is between 1 and N_t. The selected users on the same subchannel together form a channel matrix as $\boldsymbol{H}(\mathcal{Z}_n^q) = \left[\boldsymbol{h}_{0,z_1,n}^T \cdots \boldsymbol{h}_{0,z_q,n}^T \right]^T$ where $\boldsymbol{h}_{0,z_q,n}$ is $1 \times N_t$ channel coefficient vector between the BS (node 0) and node z_q and $(\cdot)^T$ is the transpose operator. When $q > 1$, this means that multiple users are supported on that subchannel and this will cause inter-user interference problem. If this problem is not overcome, performance degradation is inevitable. Thus, zero-forcing beamforming (ZF-BF) is used as a simple beamforming strategy to resolve the interference issue and the beamforming matrix is obtained as $\boldsymbol{W}(\mathcal{Z}_n^q) = \phi^{-1} \left(\boldsymbol{H}(\mathcal{Z}_n^q)^H \left(\boldsymbol{H}(\mathcal{Z}_n^q) \boldsymbol{H}(\mathcal{Z}_n^q)^H \right)^{-1} \right)$. This matrix contains $N_t \times 1$ beamforming vectors belonging to each node on subchannel n as $\boldsymbol{W}(\mathcal{Z}_n^q) = \left[\boldsymbol{w}_{0,z_1,n}, \cdots, \boldsymbol{w}_{0,z_q,n} \right]$. In the given formulas, $\phi = \sqrt{tr \left[\left(\boldsymbol{H}(\mathcal{Z}_n^q) \boldsymbol{H}(\mathcal{Z}_n^q)^H \right)^{-1} \right]}$ is used as a normalization factor and $tr(\cdot)$, $(\cdot)^H$ and $(\cdot)^{-1}$ denote matrix

trace, transpose conjugate and inverse operations, respectively. These channel and beamforming vectors are used to calculate the link data rates as.

$$R_{i,j,sub}^{(X),ts} = \mathcal{B} \log_2 \left(1 + \frac{P_{i,j,sub}^{(X),ts} ChG}{N_0 \mathcal{B}} \right) \qquad (1)$$

where X represents the communication modes, such as direct mode dm and relay mode rm, so $X \in \{dm, rm\}$, and $ts \in \{1,2\}$ is the time slot index. i and j are the transmitting and receiving nodes, respectively. i can be BS or any $Z1$ user as relay and j can be any $Z1$ user as a direct user or any $Z2$ user. $sub \in \{n, n'\}$ represents the subchannel index for time slot 1 and 2. $P_{i,j,sub}^{(X),ts}$ is the transmission power of transmitter i to receiver j on subchannel sub. ChG is the channel gain and it is defined as the $|\boldsymbol{h}_{i,j,sub} \boldsymbol{w}_{i,j,sub}|^2$ for MISO channel case and $|h_{i,j,sub}|^2$ for SISO channel case. The given channel coefficient vector for MISO channel and channel coefficient for SISO channel both include path-loss and multipath fading. Moreover, $\mathcal{B} = BW/N$, is the bandwidth of any subchannel and N_0 is the noise power spectral density.

The total data rate for the MISO-OFDMA system model by using (1) can be given as,

$$R_T = \sum_{n=1}^{N} \varpi_n^{(1)} \sum_{a=1}^{A} \rho_{0,a,n}^{(1)} R_{0,a,n}^{(dm),1} + \sum_{n'=1}^{N} \varpi_{n'}^{(2)} \sum_{a=1}^{A} \rho_{0,a,n'}^{(2)} R_{0,a,n'}^{(dm),2} \qquad (2)$$
$$+ \sum_{n=1}^{N} \sum_{n'=1}^{N} Q_{n,n'} \sum_{a=1}^{A} \sum_{b=A+1}^{A+B} \sigma_{a,b,n,n'} \min \left(R_{0,a,n}^{(rm),1}, R_{a,b,n'}^{(rm),2} \right)$$

where a and b represent the $Z1$ and $Z2$ user indexes, respectively. A and B are the total numbers of $Z1$ and $Z2$ users and $A + B$ equals to the total number of all users, K. $\varpi_n^{(1)}$, $\varpi_{n'}^{(2)}$ and $Q_{n,n'}$ are binary mode selection parameters that define if the related subchannel is allocated to direct or relay modes. If the subchannel n on time slot one is allocated to direct $Z1$ users, $\varpi_n^{(1)} = 1$, otherwise $\varpi_n^{(1)} = 0$. Moreover, if any subchannel pair in two time slots is allocated to serve a $Z2$ user, $Q_{n,n'} = 1$, otherwise $Q_{n,n'} = 0$. $\rho_{0,a,n}^{(1)}$, $\rho_{0,a,n'}^{(2)}$ and $\sigma_{a,b,n,n'}$ are also the binary indicator variables for subchannel assignment. If the BS is transmitting to $Z2$ user b with the assistance of user-relay a over subchannel pairs (n,n'), $\sigma_{a,b,n,n'}$ is one, otherwise it is zero. Moreover, if the BS is transmitting data to direct $Z1$ user a in the first time slot over subchannel n, $\rho_{0,a,n}^{(1)}$ is one, otherwise it is zero. Since, our relay type is DF, the end to end (e2e) link data rate is defined as the minimum of the link rates in two hops.

The total power consumption model for the multiple antennas scheme defined in [13] can be given as follows

$$P_T = P_C^0 + K P_C^{UE} + P_{tr} \qquad (3)$$

where $P_C^0 = N_t P_{dyn} + P_{sta}$ is the BS circuit power that P_{dyn} is the dynamic power consumption corresponding to the power radiation of all circuit blocks in each active RF chain, P_{sta} is the static power spent by cooling system, power supply etc.. P_C^{UE} is the circuit power for each user and P_{tr} is the power consumption caused by the data transmission as given follows;

$$P_{tr} = \Xi_0 \left[\sum_{n=1}^{N} \varpi_n^{(1)} \sum_{a=1}^{A} \rho_{0,a,n}^{(1)} P_{0,a,n}^{(dm),1} + \sum_{n'=1}^{N} \varpi_{n'}^{(2)} \sum_{a=1}^{A} \rho_{0,a,n'}^{(2)} P_{0,a,n'}^{(dm),2} \right]$$
$$+ \sum_{n=1}^{N} \sum_{n'=1}^{N} Q_{n,n'} \sum_{a=1}^{A} \sum_{b=A+1}^{A+B} \sigma_{a,b,n,n'} \left(\Xi_0 P_{0,a,n}^{(rm),1} + \Xi_{UE} P_{a,b,n'}^{(rm),2} \right) \quad (4)$$

where Ξ_0 and Ξ_{UE} are the power amplifier drain efficiencies.

C. Energy-Efficiency Maximization

Using the total data rate and total power values defined in Section II.B, we can now form the EE maximization problem, which is also a RRM optimization problem, for user-relay assisted MISO-OFDMA based downlink cellular networks. Unknown subchannel, power and mode selection variables for this model can be denoted as $S = \left\{ \rho_{0,a,n}^{(1)}, \rho_{0,a,n'}^{(2)}, \sigma_{a,b,n,n'} \right\}$, $\mathcal{P} = \left\{ P_{0,a,n}^{(dm),1}, P_{0,a,n'}^{(dm),2}, P_{0,a,n}^{(rm),1}, P_{a,b,n'}^{(rm),2} \right\}$ and $\Sigma = \left\{ \varpi_n^{(1)}, \varpi_{n'}^{(2)}, Q_{n,n'} \right\}$, respectively. The problem that we consider is to maximize the sum EE of all users and subchannels while also satisfying the individual QoS demands of each user as defined below;

$$\max_{\mathcal{P}, S, \Sigma} \frac{R_T (\mathcal{P}, S, \Sigma)}{P_T (\mathcal{P}, S, \Sigma)} \quad (5)$$

subject to;

C_1: $\rho_{0,a,n}^{(1)}, \rho_{0,a,n'}^{(2)}, \sigma_{a,b,n,n'}, \varpi_n^{(1)}, \varpi_{n'}^{(2)}, Q_{n,n'} \in \{0,1\}, \forall a, b, n, n'$

C_2: $\varpi_n^{(1)} + \sum_{n'=1}^{N} Q_{n,n'} = 1, \quad \forall n$

C_3: $\varpi_{n'}^{(2)} + \sum_{n=1}^{N} Q_{n,n'} = 1, \quad \forall n'$

C_4: $\sum_{a=1}^{A} \rho_{0,a,n}^{(1)} = N_t, \quad \forall n$

C_5: $\sum_{a=1}^{A} \rho_{0,a,n'}^{(2)} = N_t, \quad \forall n'$

C_6: $\sum_{n'=1}^{N} \sum_{a=1}^{A} \sum_{b=A+1}^{A+B} \sigma_{a,b,n,n'} = 1, \quad \forall n$

C_7: $\sum_{n=1}^{N} \sum_{a=1}^{A} \sum_{b=A+1}^{A+B} \sigma_{a,b,n,n'} = 1, \quad \forall n'$

C_8: $\varpi_n^{(1)} \sum_{a=1}^{A} \rho_{0,a,n}^{(1)} + \sum_{n'=1}^{N} Q_{n,n'} \sum_{a=1}^{A} \sum_{b=A+1}^{A+B} \sigma_{a,b,n,n'} \leq N_t, \forall n$

C_9: $\varpi_{n'}^{(2)} \sum_{a=1}^{A} \rho_{0,a,n'}^{(2)} + \sum_{n'=1}^{N} Q_{n,n'} \sum_{a=1}^{A} \sum_{b=A+1}^{A+B} \sigma_{a,b,n,n'} \leq N_t, \forall n'$

C_{10}: $\sum_{n=1}^{N} \varpi_n^{(1)} \sum_{a=1}^{A} \rho_{0,a,n}^{(1)} P_{0,a,n}^{(dm),1} + \sum_{n'=1}^{N} \varpi_{n'}^{(2)} \sum_{a=1}^{A} \rho_{0,a,n'}^{(2)} P_{0,a,n'}^{(dm),2} +$

$$\sum_{n=1}^{N} \sum_{n'=1}^{N} Q_{n,n'} \sum_{a=1}^{A} \sum_{b=A+1}^{A+B} \sigma_{a,b,n,n'} \left(P_{0,a,n}^{(rm),1} + P_{a,b,n'}^{(rm),2} \right) \leq P_{max}$$

C_{11}: $P_{0,a,n}^{(dm),1}, P_{0,a,n'}^{(dm),2}, P_{0,a,n}^{(rm),1}, P_{a,b,n'}^{(rm),2} \geq 0, \quad \forall a, b, n, n'$

C_{12}: $\sum_{n=1}^{N} \varpi_n^{(1)} \rho_{0,a,n}^{(1)} R_{0,a,n}^{(dm),1} + \sum_{n'=1}^{N} \varpi_{n'}^{(2)} \rho_{0,a,n'}^{(2)} R_{0,a,n'}^{(dm),2} \geq R_a^{req}, \forall a$

C_{13}: $\sum_{n=1}^{N} \sum_{n'=1}^{N} Q_{n,n'} \sum_{a=1}^{A} \sigma_{a,b,n,n'} \min \left(R_{0,a,n}^{(rm),1}, R_{a,b,n'}^{(rm),2} \right) \geq R_b^{req}, \forall b$

In (5), C_1 is an integer constraint so that the subchannel allocation indicators and mode selection parameters are binary variables. C_2 and C_3 guarantee that each subchannel in each time slot will serve either direct or relayed users. C_4 and C_5 say that N_t direct users can be supported on each subchannel for each time slot, if direct mode is selected. C_6 and C_7 limit the number of supported relayed users to one, if relay mode is selected. In C_8 and C_9, it is shown that maximum N_t nodes can be supported on each subchannel in each time slot. C_{10} puts a limit for the total power consumption and C_{11} is the non-negative power constraint. C_{12} and C_{13} guarantee the required data rates for $Z1$ and $Z2$ users, respectively.

III. ENERGY-EFFICIENT SOLUTION FOR MISO-OFDMA

The defined optimization problem in (5) is a mixed combinatorial and non-convex optimization problem which is very hard to solve. The optimization problem belongs to a class of optimization problems called fractional programming (FP) problem, since the objective function is the ratio of the total capacity to the total consumed power. The fractional form of the objective function makes the problem solution more difficult. In this section, we will decompose the problem into two sub-problems and propose a RRM solution to make this problem more tractable.

A. Proposed Mode Selection and Subchannel Allocation

In the first step of the solution, a heuristic mode selection and subchannel allocation algorithm is proposed by assuming equal power allocation among subchannels. The relay candidate r_b, for any $Z2$ user b is selected as the nearest $Z1$ user. Let $\mathbb{A}$ and $\mathbb{B}$ be the sets of $Z1$ and $Z2$ users, respectively and $d_{b,a}$ is the distance between $Z1$ user a and $Z2$ user b. Thus, the relay candidate for $Z2$ user b can be chosen as $r_b = \{ a \mid min\{d_{b,a}\}, \ a \in \mathbb{A} \}$. On each subchannel, according to the initial user selection to be served, mode selection is performed. If the direct mode is selected, multiple users are served simultaneously, but when the relay mode is selected, only one user is served on that subchannel. It is assumed that, the same subchannels $(n = n')$ in two consecutive time slots are allocated to the same direct users or the same relayed user, as shown in Figure 2. In multiple user allocation scheme, the subchannel power is also allocated equally among the users allocated to the related subchannel. As mentioned earlier, the relay protocol is DF so the e2e data rate equals the minimum of those in the first and second hops. They are assumed to be

equal in this study, $R_{0,r_b,n}^{(rm),1} = R_{r_b,b,n}^{(rm),2}$. It is a reasonable assumption from EE point of view, since when they are not equal, the system EE will be reduced as data will be either wasted or stored with additional buffers. Hence, the two hops must be balanced. Using this assumption, the relationship between the power values allocated to the first and second hops can be derived as $P_{0,r_b,n}^{(rm),1} = P_{r_b,b,n}^{(rm),2} \mathcal{g}$ where $\mathcal{g} = \frac{|h_{r_b,b,n}|^2}{|\boldsymbol{h}_{0,r_b,n}\boldsymbol{w}_{0,r_b,n}|^2}$. In the light of above assumptions, the proposed heuristic mode selection and subchannel allocation algorithm for the MISO-OFDMA scheme is outlined in Algorithm 1.

***Algorithm 1**: Proposed Mode Selection and Subchannel Allocation*

o Let $\mathbb{A}$, $\mathbb{B}$, $\mathbb{S}$ and $\mathbb{U}$ are the set of $Z1$, $Z2$, satisfied and unsatisfied users, respectively. $\mathbb{K} = \mathbb{A} \cup \mathbb{B}$ is the set of total users.
o Initially, $\mathbb{S} = \emptyset$, $\mathbb{U} = \mathbb{K}$, $\mathbb{N} = \{1,2,\dots,N\}$.
o $p_n = P_{max}/N$, $\forall n \in \mathbb{N}$, $\nabla_k = R_k^{req}$, $\forall k \in \mathbb{K}$, $R_T = 0$, $P_{tr} = 0$.
Part 1
while $\mathbb{U} \neq \emptyset$ and $\mathbb{N} \neq \emptyset$ **do**
1: Set $q = 1$ and $\mathcal{Z}_n^q = \emptyset, \forall n \in \mathbb{N}$.
2: Find the initial user, $k^* = \arg\max_{k \in \mathbb{U}}(\nabla_k)$.
3: **If** k^* is direct user **do**
  3.1: Calculate e2e data rate of user k^* by using (1),
      $\Delta_{k^*}^n = \sum_{ts=1}^2 R_{0,k^*,n}^{(dm),ts}$, $\forall n$ where $P_{0,k^*,n}^{(dm),1} = P_{0,k^*,n}^{(dm),2} = p_n/(2N_t)$
  3.2: Find best subchannel for user k^*; $n^* = \arg\min_{n \in \mathbb{N}}|\Delta_{k^*}^n - \nabla_{k^*}|$.
  3.3: Set $\varpi_{n^*}^{(1)} = \varpi_{n^*}^{(2)} = 1$ and $\rho_{0,k^*,n^*}^{(1)} = \rho_{0,k^*,n^*}^{(2)} = 1$
  3.4: Update the user-set $\mathcal{Z}_{n^*}^q = \{k^*\}$ and $\boldsymbol{H}(\mathcal{Z}_{n^*}^q) = \boldsymbol{h}_{0,k^*,n^*}$.
  3.5: Add new direct users
    for $q = 2:N_t$ **do**
    • $\boldsymbol{P}_q^{\perp} = \boldsymbol{I}_{N_t} - \boldsymbol{H}(\mathcal{Z}_{n^*}^{(q-1)})^H (\boldsymbol{H}(\mathcal{Z}_{n^*}^{(q-1)})\boldsymbol{H}(\mathcal{Z}_{n^*}^{(q-1)})^H)^{-1} \boldsymbol{H}(\mathcal{Z}_{n^*}^{(q-1)})$
       where $\boldsymbol{I}_{N_t}$ is $N_t \times N_t$ identity matrix.
    • Calculate $g_{a,n^*} = \boldsymbol{h}_{0,a,n}\boldsymbol{P}_q^{\perp}\boldsymbol{h}_{0,a,n}^H$, $\forall a \in \mathbb{A}$ where $a \notin \mathcal{Z}_{n^*}^{(q-1)}$
    • Select the user that satisfies, $a^+ = \arg\max_a(g_{a,n^*})$
    • Set $\rho_{0,a^+,n^*}^{(1)} = \rho_{a^+,n^*}^{(2)} = 1$
    • $\mathcal{Z}_{n^*}^q = \mathcal{Z}_{n^*}^{(q-1)} \cup \{a^+\}$, $\boldsymbol{H}(\mathcal{Z}_{n^*}^q) = [\boldsymbol{H}(\mathcal{Z}_{n^*}^{(q-1)})^T \, \boldsymbol{h}_{0,a^+,n^*}^T]^T$
    end for
  3.6: Calculate the final e2e rates of each user $\Delta_s^{n^*}, \forall s \in \mathcal{Z}_{n^*}^q$ as in step *3.1*.
  3.7: Update $R_T = R_T + \sum_s \Delta_s^{n^*}$, $P_{tr} = P_{tr} + \Xi_0 p_{n^*}$.
  3.8: Update $\nabla_s = \nabla_s - \Delta_s^{n^*}$ and if $\nabla_s \leq 0$ then, $\mathbb{S} \leftarrow \mathbb{S} \cup \{s\}$, $\mathbb{U} \leftarrow \mathbb{U} \setminus \{s\}$.
  Elseif k^* is relayed user **do**
  3.9: Calculate e2e data rate of user k^* for $\forall n \in \mathbb{N}$ by using (1),
      $\Delta_{k^*}^n = \min(R_{0,r_{k^*},n}^{(rm),1}, R_{r_{k^*},k^*,n}^{(rm),2}) = R_{0,r_{k^*},n}^{(rm),1} = R_{r_{k^*},k^*,n}^{(rm),2}$
      where $P_{0,r_{k^*},n}^{(rm),1} = p_n \frac{\mathcal{g}}{1+\mathcal{g}}$, $P_{r_{k^*},k^*,n}^{(rm),2} = p_n \frac{1}{1+\mathcal{g}}$.
  3.10: Find best subchannel n^* similar to *3.2* and set $\mathcal{Q}_{n^*,n^*} = 1$.
  3.11: Update $\mathcal{Z}_{n^*}^q = \{k^*\}$ and set $\sigma_{r_{k^*},k^*,n^*,n^*} = 1$. Do not add any more users to n^*.
  3.12: Calculate the data rate of user k^*, $\Delta_{k^*}^{n^*}$ as in *3.9*.
  3.13: Update $R_T = R_T + \Delta_{k^*}^{n^*}$, $P_{tr} = P_{tr} + \Xi_0\left(p_{n^*}\frac{\mathcal{g}}{1+\mathcal{g}}\right) + \Xi_{UE}\left(p_{n^*}\frac{1}{1+\mathcal{g}}\right)$.
  3.14: $\nabla_{k^*} = \nabla_{k^*} - \Delta_{k^*}^{n^*}$ and if $\nabla_{k^*} \leq 0$ then, $\mathbb{S} \leftarrow \mathbb{S} \cup \{k^*\}$, $\mathbb{U} \leftarrow \mathbb{U} \setminus \{k^*\}$.
  end if
4: $\mathbb{N} \leftarrow \mathbb{N} \setminus \{n^*\}$.
end while
Part 2
while $\mathbb{N} \neq \emptyset$ **do**
1: Set $q = 1$ and $\mathcal{Z}_n^q = \emptyset$ $\forall n \in \mathbb{N}$.
2: Calculate Δ_a^n as in *3.1* and EE metric $e_a = \frac{R_T + \Delta_a^n}{P_C^0 + KP_C^{UE} + P_{tr} + \Xi_0 p_n}$, $\forall a \in \mathbb{A}$.
3: Find user $a^* = \arg\max_{a \in \mathbb{A}}(e_a)$ and $\mathcal{Z}_n^q = \{a^*\}$, $\boldsymbol{H}(\mathcal{Z}_n^q) = \boldsymbol{h}_{0,a^*,n}$.
4: Add new users similar to *3.5* and apply *3.6* and *3.7*. $\mathbb{N} \leftarrow \mathbb{N} \setminus \{n\}$.
end while

In this algorithm, we perform mode selection and subchannel allocation separately to make the solution simple and practical. In Part 1, mode selection and subchannel allocation are applied in order to fulfill the minimum rate requirements of all users. In this part, mode selection is performed according to the QoS demands of the users. The user whose QoS demand is highest is selected as the initial user and the mode will be determined according to this user's location in the cellular area. If the direct mode is selected, multiple users will be served on the selected subchannel. While, allocating new users, it is important that the new users must be as much as orthogonal to the already selected users on related subchannel so a projection matrix $\boldsymbol{P}^{\perp}$ is calculated to determine the orthogonal users. Totally, N_t users are supported on each subchannel simultaneously. If the relay mode is selected, only one link will be active for each subchannel and no more users will be allocated to the related subchannel. If all users are satisfied in Part 1 and there are still remaining subchannels, subchannel allocation is performed for only direct mode in Part 2 and multiple users are allocated for each subchannel. The user who makes the EE metric maximum is selected as the initial user on any unallocated subchannel and then the new users are admitted to this subchannel similar to Part 1. This part is terminated when all subchannels are allocated.

B. Power Allocation

The original optimization problem defined in (5) can be transformed to a power allocation problem as in (6), since the mode selection and subchannel allocation have already been performed.

$$\max_{\mathcal{P}} \frac{R_T^{\dagger}(\mathcal{P})}{P_T^{\dagger}(\mathcal{P})} \qquad (6)$$

subject to;

$$C_1^{\dagger}: \sum_{a=1}^{A} \sum_{n \in F_a} \left(P_{0,a,n}^{(dm),1} + P_{0,a,n}^{(dm),2}\right)$$
$$+ \sum_{b=A+1}^{A+B} \sum_{n \in F_b} \left(P_{0,r_b,n}^{(rm),1}\left(1 + \frac{1}{\mathcal{g}}\right)\right) \leq P_{max}$$
$$C_2^{\dagger}: \sum_{n \in F_a} \left(R_{0,a,n}^{(dm),1} + R_{0,a,n}^{(dm),2}\right) \geq R_a^{req}, \forall a$$
$$C_3^{\dagger}: \sum_{n \in F_b} R_{0,r_b,n}^{(rm),1} \geq R_b^{req}, \forall b$$
$$C_4^{\dagger}: P_{0,a,n}^{(dm),1}, P_{0,a,n}^{(dm),2}, P_{0,r_b,n}^{(rm),1}, P_{r_b,b,n}^{(rm),2} \geq 0, \quad \forall a,b,n$$

where F_a and F_b represent the subchannel sets allocated to $Z1$ user a and $Z2$ user b, respectively. Moreover, $R_T^{\dagger}(\mathcal{P})$ and $P_T^{\dagger}(\mathcal{P})$ values defined in the objective function can be formulated as below.

$$R_T^{\dagger}(\mathcal{P}) = \sum_{a=1}^{A} \sum_{n \in F_a} \left(R_{0,a,n}^{(dm),1} + R_{0,a,n}^{(dm),2}\right) + \sum_{b=A+1}^{A+B} \sum_{n \in F_b} R_{0,r_b,n}^{(rm),1} \qquad (7)$$

$$P_T^\dagger (\mathcal{P}) = P_C^0 + KP_C^{UE} + \Xi_0 \sum_{a=1}^{A} \sum_{n \in F_a} \left(P_{0,a,n}^{(dm),1} + P_{0,a,n}^{(dm),2} \right)$$
$$+ \sum_{b=A+1}^{A+B} \sum_{n \in F_b} \left(P_{0,r_b,n}^{(rm),1} \left(\Xi_0 + \frac{\Xi_{UE}}{\mathcal{G}} \right) \right) \tag{8}$$

It can be seen that the rewritten problem in (6) has been recovered from integer variables so we do not need to consider the combinatorial nature of the problem. However, the problem is still non-convex because of the fractional form of the objective function. To deal with the fractional objective function, we can transform the objective function in (6) into an equivalent form as $\max_{\mathcal{P}} \left(R_T^\dagger (\mathcal{P}) - eP_T^\dagger (\mathcal{P}) \right)$, which is convex with respect to the power allocation variables, and solve it by using Dinkelbach's method [21]. For defined equivalent form, e represents the EE parameter. The solution to this modified problem is outlined in Algorithm 2.

***Algorithm 2**: Dinkelbach-Lagrange Dual Decomposition for EE*

∘ Set $\sigma = 0$, $\epsilon_{out} > 0$, $e_\sigma = 0$
while $|e_\sigma - e_{\sigma-1}| > \epsilon_{out}$ **do**
1: Solve the optimization problem (6) with the equivalent objective function.
  1.1:Set $i = 0$, ϵ_χ , ϵ_κ , $\epsilon_\varphi > 0$
  while $|\chi^i - \chi^{i-1}| > \epsilon_\chi$ **and** $|min(\kappa^i - \kappa^{i-1})| > \epsilon_\kappa$ **and** $|min(\varphi^i - \varphi^{i-1})| > \epsilon_\varphi$ **do**
    ∘ Find the optimal power values $\mathcal{P}^*$ by using (9)-(11).
    ∘ Increase i by 1.
    ∘ Update the Lagrange multipliers by using (12)-(14).
  end while
2:Increase σ by 1.
3:Update EE parameter $e_\sigma = R_T^\dagger (\mathcal{P}^*)/P_T^\dagger (\mathcal{P}^*)$
end while

The given algorithm is based on the Dinkelbach algorithm which is an iterative algorithm [21]. It has both outer and inner iterations. In the outer iterations symbolized by σ, the EE parameter is updated according to the optimal power values $\mathcal{P}^*$ obtained in the inner iterations symbolized by i. Outer iterations are terminated according to the predefined threshold value ϵ_{out}. The Dinkelbach method produces an increasing sequence of e values, which converges to the optimal value at a superlinear convergence rate [21]. In the presented algorithm, we have to solve the optimization problem (6) by replacing the objective function with the defined equivalent form in order to obtain optimal power values in an inner loop. Since the transformed power allocation optimization problem is convex now, it can be solved with any standard convex optimization method. In this part, we will apply the dual decomposition method since the convex problem satisfies the Slater's condition so strong duality holds. The Lagrange function belongs to the problem is defined as, $\mathcal{L}(\mathcal{P}, \chi, \kappa, \varphi) = R_T^\dagger (\mathcal{P}) - eP_T^\dagger (\mathcal{P}) + \chi \left[P_{max} - \sum_{a=1}^{A} \sum_{n \in F_a} \left(P_{0,a,n}^{(dm),1} + P_{0,a,n}^{(dm),2} \right) + \sum_{b=A+1}^{A+B} \sum_{n \in F_b} \left(P_{0,r_b,n}^{(rm),1} \left(1 + \frac{1}{\mathcal{G}} \right) \right) \right] + \sum_{a=1}^{A} \kappa_a \left[\sum_{n \in F_a} \left(R_{0,a,n}^{(dm),1} + \right. \right.$

$\left. \left. R_{0,a,n}^{(dm),2} \right) - R_a^{req} \right] + \sum_{b=A+1}^{A+B} \varphi_b \left[\sum_{n \in F_b} R_{0,r_b,n}^{(rm),1} - R_b^{req} \right]$ where χ, $\kappa = [\kappa_1, \kappa_2, ..., \kappa_A]$ and $\varphi = [\varphi_{A+1}, \varphi_{A+2}, ..., \varphi_{A+B}]$ are nonnegative Lagrange multipliers associated with the constraints $C_1^\dagger - C_3^\dagger$ respectively. Then, the dual Lagrangian function can be written as $\hbar(\chi, \kappa, \varphi) = \max_{\mathcal{P}} \mathcal{L}(\mathcal{P}, \chi, \kappa, \varphi)$ and the dual optimization problem can be defined as $\min_{\chi, \kappa, \varphi \geq 0} \hbar(\chi, \kappa, \varphi)$. This dual problem is divided into a master problem and a sub-problem, and an iterative approach is adopted to solve it. In the sub-problem, optimal power values are obtained for fixed Lagrangian multipliers, whereas by resolving the master problem, we update χ, κ and φ. This process is continued until the desired convergence is achieved.

By employing the Karush-Kuhn-Tucker (KKT) conditions, we can find the optimal power values as follows;

$$P_{0,a,n}^{*(dm),1} = \left[\frac{\mathcal{B}(\kappa_a + 1)}{(e\Xi_0 + \chi)ln2} - \frac{1}{\pi_{0,a,n}^1} \right]^+ \tag{9}$$

$$P_{0,a,n}^{*(dm),2} = \left[\frac{\mathcal{B}(\kappa_a + 1)}{(e\Xi_0 + \chi)ln2} - \frac{1}{\pi_{0,a,n}^2} \right]^+ \tag{10}$$

$$P_{0,r_b,n}^{*(rm),1} = \left[\frac{\mathcal{B}(\varphi_b + 1)}{\left(e \left(\Xi_0 + \frac{\Xi_{UE}}{\mathcal{G}} \right) + \chi \left(1 + \frac{1}{\mathcal{G}} \right) \right) ln2} - \frac{1}{\pi_{0,r_b,n}^1} \right]^+ \tag{11}$$

where $\pi = \frac{ChG}{N_0 \mathcal{B}}$ represents the channel to noise ratio value and $[x]^+ = max(0, x)$. $P_{r_b,b,n}^{*(rm),2}$ can also be determined by using the relationship $P_{0,r_b,n}^{*(rm),1} = P_{r_b,b,n}^{*(rm),2} \mathcal{G}$.

The dual variables χ, κ and φ can be iteratively updated by using the subgradient method,

$$\chi^{i+1} = \left[\chi^i - \vartheta_1^i \left(P_{max} - \sum_{a=1}^{A} \sum_{n \in F_a} \left(P_{0,a,n}^{*(dm),1} + P_{0,a,n}^{*(dm),2} \right) \right. \right.$$
$$\left. \left. + \sum_{b=A+1}^{A+B} \sum_{n \in F_b} \left(P_{0,r_b,n}^{*(rm),1} \left(1 + \frac{1}{\mathcal{G}} \right) \right) \right) \right]^+ \tag{12}$$

$$\kappa_a^{i+1} = \left[\kappa_a^i - \vartheta_2^i \left(\sum_{n \in F_a} \left(R_{0,a,n}^{(dm),1} + R_{0,a,n}^{(dm),2} \right) - R_a^{req} \right) \right]^+ \tag{13}$$

$$\varphi_b^{i+1} = \left[\varphi_b^i - \vartheta_3^i \left(\sum_{n \in F_b} R_{0,r_b,n}^{(rm),1} - R_b^{req} \right) \right]^+ \tag{14}$$

where ϑ_1^i, ϑ_2^i and ϑ_3^i are the constant step sizes. The convergence proof of the subgradient method for constant step size is given in [22].

IV. NUMERICAL RESULTS AND DISCUSSION

In this part, numerical results are given in order to evaluate the performance of the proposed RRM solution for the EE maximization defined for the MISO-OFDMA user-relay assisted cellular networks. In our simulation, parameters from

3GPP LTE standard are used [23][24]. Extended Pedestrian A (EPA) is used as the multipath channel model. The path-loss in dB between the BS and the UEs and between the user-relays and UEs are modeled as $128.1 + 37.6\,log10\,d$ and $148 + 40\,log10\,d$, respectively, with distance d in kilometers. The total bandwidth, BW is 5 Mhz, the number of subchannels, N is 25 and the noise power spectral density, N_0 is -174 dbm/Hz. The distances D_1 and D_2, which are used to separate the cellular area into two zones, are set to 750m and 375m, respectively. We have followed the power consumption model defined in [13]. Unless stated elsewhere, the values of P_{dyn} and P_{sta}, which are used to calculate the P_C^0, are set to 35 dBm and $P_C^{UE} = 0.1$ W. Moreover, Ξ_0 and Ξ_{UE} values are selected as 2.5 and 1, respectively. In the following, if it is not stated elsewhere, one user from $Z1$ zone and one user from $Z2$ zone will have a minimum data rate requirement constraint. Simulation results are obtained by averaging 1000 channel realizations.
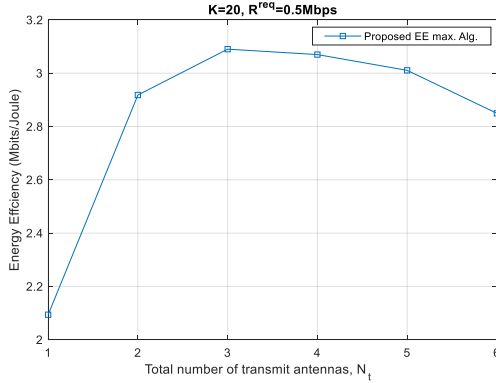

Fig. 3. EE versus total number of transmit antennas

A. Effect of the number of transmit antennas

In this part, we will determine the optimum number of transmit antennas that maximize the EE for the defined system. As mentioned earlier, increasing the number of transmit antennas not only increases the system capacity but also increases the consumed power because of the increasing RF chains. Thus, it is important to find an optimal number of antennas in terms of EE. In Figure 3, EE is plotted as a function of the number of transmit antennas. We can see that the EE of the proposed EE maximization scheme for MISO-OFDMA increase until a certain value of N_t and then it starts to decrease. According to our simulation parameters, the optimal number of transmit antennas is 3 as illustrated in Figure 3. However, it was shown in [13] that changing the system parameters, such as the number of users, P_{dyn} and P_{sta}, can change this optimal value, since it depends on the simulation parameters. It is clear that using multiple antennas provides additional degrees of freedom such as spatial diversity gain and it increases the sum rate of the system. However, it also increases the total power consumption. When N_t is small, the sum rate increment is much more than the total power consumption and this provides higher EE, however, for large N_t, this effect is opposite. According to this result, in the

rest of the simulations total number of transmit antennas N_t is set to 3, if it is not stated elsewhere.

B. Effect of dynamic power consumption

In our power consumption model, the BS circuit power has a dynamic part (P_{dyn}) and this part affects the power consumption proportional to the number of transmit antennas as given in (3). In Figure 4, we examine how the EE for proposed EE maximization for MISO-OFDMA and the existing capacity maximization for MISO-OFDMA schemes change with dynamic power consumption. In the existing capacity maximization scheme, the objective function of the problem is changed as maximizing the capacity but the constraints are the same for both algorithms. We can see that the proposed algorithm offers significant gain over existing algorithm in terms of EE, especially when P_{dyn} is small. This is caused by that the effect of the data transmission power on the total power consumption is higher for small P_{dyn} values and the proposed scheme provides relatively low data transmission power. For high P_{dyn} values, the effect of data transmission power on the total power consumption is suppressed so both algorithms perform almost equally.
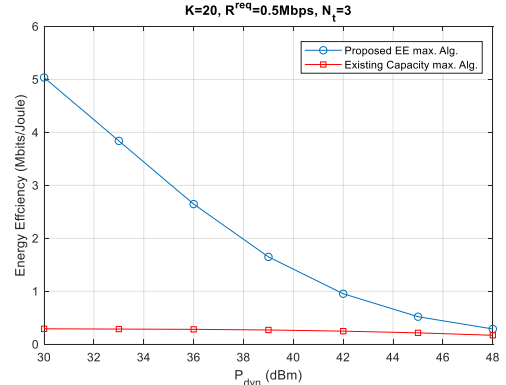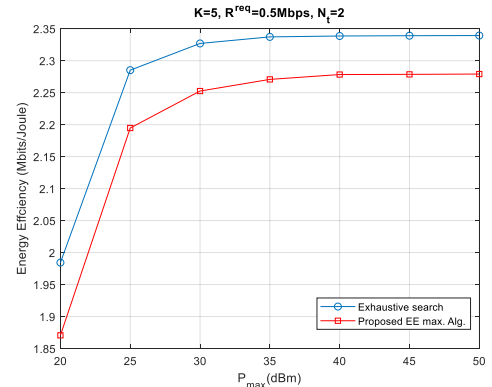

Fig. 4. Effect of the P_{dyn} on the system EE

Fig. 5. EE performance comparison with the exhaustive search

C. Performance Comparison

In this part, the EE performance of the proposed solution is compared with the exhaustive search as a benchmark. In Figure 5, the system performance is compared in terms of EE As expected exhaustive search outperforms the proposed solution on system EE. However, the computational load is

also a very crictical metric in multi-antenna, multi-relay, multi-user and multi-carrier networks for practical implementation. It is calculated by measuring the average execution time of the compared solutions. Average execution time measurement is one of the valuable performance metrics that is mostly used to compare the complexity of the algorithms in a simulation environment. The results are obtained by using MATLAB R2017b on a PC with Core i7 − 4770 processor operating with a clock 3.4 GHz. According to the results given in Table 1, it is observed that the computational burden on the system is lighter with the proposed solution.

Table 1. Average execution time (sec) of the algorithms (P_{max}= 45 dBm)

Algorithm	Average execution time (sec)
Proposed	15.12
Exhausted Search	24.48

D. EE and SE for different system parameters

It is well-known that there is a trade-off between the EE and SE and it has been studied in many works for different wireless communication scenarios [6][10][12][17]. Thus, in this part, in the light of the existing literature, we will also examine this trade-off for our scenario by comparing the proposed EE maximization for MISO-OFDMA scheme with the existing capacity maximization for MISO-OFDMA scheme for different system parameters. As mentioned in Section IV.B, in the existing capacity maximization scheme, the objective function is changed but the constraints are kept the same. This algorithm is used in many works as a benchmark algorithm to examine the EE and SE trade-off [6][10][12][17].

Figures 6 and 7 illustrate the EE and total data rates of the MISO-OFDMA based user-relay assisted cellular networks under different maximum allowed transmit power, P_{max}. In these figures, the proposed EE maximization scheme is compared with the existing capacity maximization scheme by changing the number of users between 10 and 25. In Figure 6, it is seen that the EE is the same till $P_{max} = 30$ dBm for both algorithms. However, after that value, the gap between two algorithms in terms of EE is dramatically increasing with higher values of P_{max}. Although, the EE of the proposed scheme saturates, the EE of the existing capacity maximization scheme decreases sharply since this algorithm still allocates power in order to increase the total data rate by sacrificing EE. Another important observation from this figure is the EE increases with the increment of the number of users because of the multiuser diversity. In Figure 7, it is observed that the total data rate values are similar in low P_{max} regimes. After 30 dBm, the total data rate value is increasing for capacity maximization scheme since it goes on using transmission power, but it remains same for the proposed scheme. The effect of multiuser diversity can also be seen from this figure in which the total data rate is increasing for both algorithms for higher number of users.
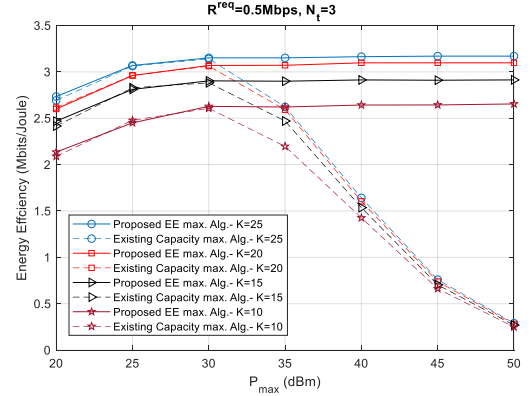

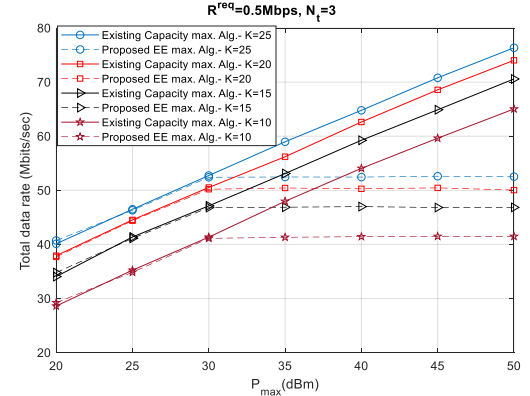Fig. 6. MISO-OFDMA-EE vs P_{max} for different number of users.

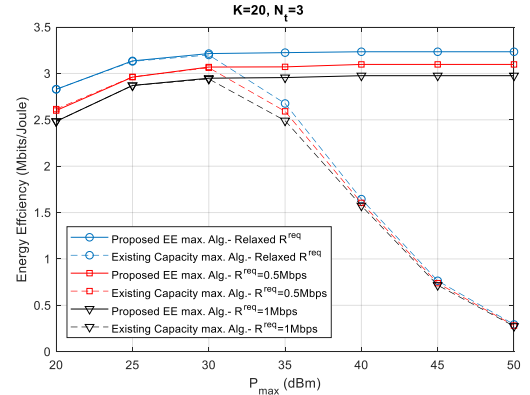Fig. 7. MISO-OFDMA-Total data rate vs P_{max} for different number of users.

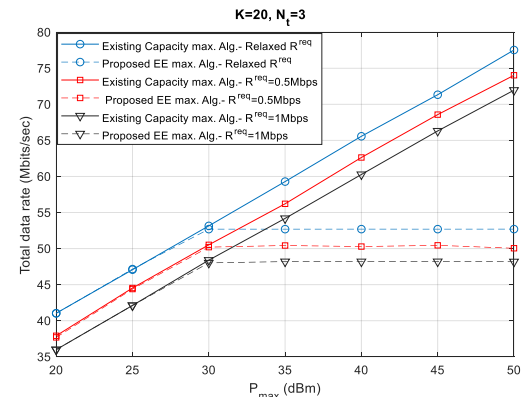Fig. 8. MISO-OFDMA-EE vs P_{max} for different R^{req}.

Fig. 9. MISO-OFDMA-Total data rate vs P_{max} for different R^{req}

We have focused on the effect of the minimum required data rates on EE and SE in Figures 8 and 9. Different data rate constraints are applied as $R^{req} = 0$ Mbps which is called as *relaxed* R^{req} scheme in the figures, $R^{req} = 0.5$ Mbps and $R^{req} = 1$ Mbps. EE of the system is illustrated in Figure 8 and total data rate is shown in Figure 9. As expected, decreasing the minimum required data rates causes higher EE and total data rate performances. When relaxing R^{req} constraints, the algorithm does not have to spend much effort to satisfy the users who are in bad conditions. The users, who have better channel gains, will be served and this will increase the EE and total data rate.

E. Effect of the cell-radius

We have examined the effect of the cell-radius on the EE for the proposed EE maximization and existing capacity maximization algorithms for MISO-OFDMA in Figure 10. The cell-radius increment decreased the EE performance for both algorithms.
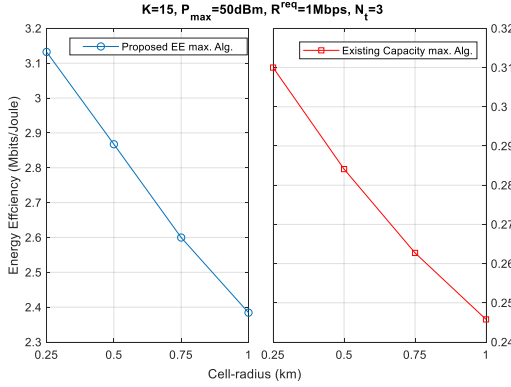

Fig. 10. MISO-OFDMA-Effect of the cell-radius on the EE

F. Convergence of the proposed algorithm

In this part, the convergence of the proposed solution will be discussed. The number of outer iterations that updates Dinkelbach parameter and the number of inner iterations that updates the Lagrange multipliers are obtained for different number of users and different number of transmit antennas. In Figure 11, it is seen that the Dinkelbach parameter value converges only in 3 iterations and the dual decomposition technique converges almost in 40 iterations independent of the total number of users and number of transmit antennas.
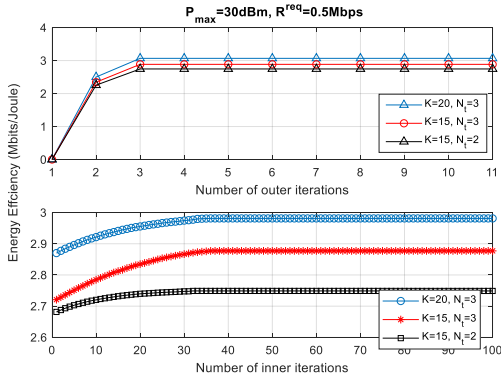

Fig. 11. Number of outer and inner iterations for the proposed solution

V. CONCLUSIONS AND FUTURE WORKS

We have studied the EE maximization problem for the combination of OFDMA, multi-antenna transmission technology and user-relaying by considering the QoS demands of the users. The EE maximization problem is hard to solve in its original form since it is a mixed combinatorial and non-convex optimization problem. To simplify the problem and to make it practically used, the problem is decomposed into parts. A radio resource management solution is proposed and subchannel allocation, mode selection and power allocation are performed separately. To discuss the performance of the proposed scheme, numerical results are obtained and effect of the different system parameters are examined. The EE and SE trade-off is revealed and the proposed scheme has been compared with the exhaustive search in terms of EE performance and computational complexity. In our future work, we will carry out the EE maximization problem for novel 5G platforms such as massive MIMO, non-orthogonal multiple access (NOMA) and ultra-dense heterogeneous networks [25][26].

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