Energy-Efficient Resource Allocation in NOMA-based HCN Systems

M.Moltafet and P. Azmi

***Abstract*—In this paper, the energy efficient resource allocation in NOMA-based heterogeneous cellular network (HCN) systems is investigated. Since energy consumption and its limitations is one of the important challenges in fifth generation of cellular networks (5G), we propose a resource allocation problem which allocates power and subcarriers to multiple users to achieve the best system energy efficiency (EE). To solve the corresponding problem an iterative algorithm is used. In each iteration power and subcarrier are assigned separately. In each iteration, to solve the power allocation problem dual method considering successive convex approximation (SCA) approach is used, and to solve the subcarrier allocation problem, mixed integer non-linear programing (MINLP) of optimization toolboxes is applied. The effectiveness of this resource allocation method is illustrated in simulation results section.**

***Index Terms*– NOMA, Energy Efficiency, resource allocation, HCN,**

I. INTRODUCTION

Statistical data show that wireless communication systems consume 0.5% of global energy consumption [1]. The wireless users and their required date rate are exponentially increasing and the required data traffic by approximately become doubling every year [2]. Therefore, energy consumption and its limitation is one of the important challenges for the next generation of cellular networks (5G). To manage this issue, new approaches in multiple access (MA) techniques, system model and resource allocation should be applied. Non-orthogonal multiple access (NOMA) is one of the promising MA techniques in 5G. Based on NOMA approach each subcarrier can be assigned to more than one user in a cell simultaneously. In this technique each subcarrier can be assigned to multiple users by applying superposition coding (SC) on transmitter side, and on the receiver side, each user obtains it's signal by using successive interference cancellation (SIC). In [3], the authors introduced bit/Joule to investigate the energy efficiency (EE) of a cognitive radio system and then developed an efficient resource allocation algorithm. In [4], a resource allocation method for energy saving (ES) in a heterogeneous cellular network (HCN) system is studied. In [5], the authors studied an optimal base station (BS) density for both homogeneous and heterogeneous cellular networks, where they considered that the transmitted power from all BSs is fixed. An algorithm to minimize total power consumption in cellular system is proposed in [6]. In [7], the authors proposed a resource allocation algorithm for maximizing the EE in a orthogonal frequency division multiple access (OFDMA)-based system with perfect hannel state information at the transmitter (CSIT). Traffic-aware transmission methods are proposed to increase the EE in [8] and [9], where BSs based on the traffic loads can switch to different modes such as sleep mode and shut off mode. In [10] and [11], the authors investigated about SC and SIC. The performance of a NOMA-based system by using fractional transmit power allocation is investigated in [12]. In [13], the information theory aspect of NOMA technique is studied. In [14], a radio resource allocation method for heterogeneous traffic in generalized frequency division multiple access (GFDM)-NOMA-based HCN system is investigated, and to solve the resource allocation problem different successive convex approximation (SCA) method is used.

The main contributions of this paper are summarized as follows:

- NOMA technique, HCN technology and energy efficient resource allocation methods can offer considerable promise to decrease energy consumption in cellular system. Therefore, we consider energy efficient resource allocation in NOMA-based HCN system.
- We propose a novel resource allocation method to maximize system EE of a NOMA-based HCN system. The constraints of our problem are, users minimum rate requirement, maximum available power in the system, and NOMA constraint.
- The proposed problem is non-convex with high complexity. To tackle the non-convexity issue we use an iterative method by applying SCA method and fractional programing, where in each iteration power and subcarrier allocation are updated separately. The power allocation problem is solved by applying SCA approach and using dual method, and the subcarrier allocation problem is mixed integer non-linear programing (MINLP) and can be solved by an available software of optimization toolboxes. The remainder of this paper is organized as follows: The system model and problem formulation are presented in Section II. The solution algorithm is investigated in Section III. Complexity discussion is presented in Section

M. Moltafet with the Department of Electrical and Computer Engineering, Tarbiat Modares University, Tehran Iran, m.moltafet@modares.ac.ir. P.Azmi Corresponding author, Full Professor, with the Department of Electrical and computer Engineering, Tarbiat Modares University, Tehran Iran, pazmi@modares.ac.ir.

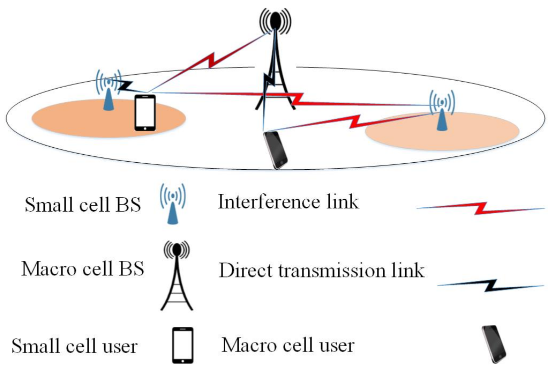

Fig. 1: A typical illustration of considered system model.

IV. Simulation results are presented in Section V. Finally, conclusion is given in Section VI.

II. SYSTEM MODEL AND PROBLEM FORMULATION

We consider a downlink communication scenario of NOMA-based HCN system where users are randomly deployed in it. A typical illustration of considered system model is shown in Fig. 1.

In the considered system model parameters are supposed as follows: $p^f_{s,n}$ indicates the assigned power to user s from BS f over subcarrier n, $h^f_{s,n}$ denotes the channel between user s and BS f on sub-carrier n, $\nu^f_{s,n}$ is a binary variable which shows the subcarrier assignment, i.e., if subcarrier n assigned to user s over BS f we have $\nu^f_{s,n}=1$, otherwise, $\nu^f_{s,n}=0$, $\boldsymbol{P}$ and $\boldsymbol{\nu}$ are the matrices of power and subcarrier (respectively) by size $S\times N\times F$ where S is the total number of users, N is the total number of subcarriers and F is the total number of BSs. Moreover, the set of BSs is shown by $\mathcal{F}=\{1,2,\dots,F\}$ where macro base station (MBS) is shown by $f=1$, the set of all users in BSs f is shown by $\mathcal{S}_f=\{1,2,\dots,S_f\}$ where $\bigcup_{f\in\mathcal{F}}S_f=S$, and the set of all subcarriers is denoted by $\mathcal{N}=\{1,2,\dots,N\}$. Also, the notations $\mathbf{p}^f_s=[p^f_{s,1},\dots,p^f_{s,N}]^T$, $\mathbf{P}^f=[p^f_1,\dots,p^f_{S_f}]^T$ and $\mathbf{P}=[\mathbf{P}^1,\dots,\mathbf{P}^F]$.

For the signal model, NOMA approach is considered. In this approach the users are sorted based on their channels gain and each subcarrier can be assigned to more than one user. Based on NOMA approach in each subcarrier a user can removes the other users signals which have worse channel than that's channel and the other users signals are considered as noise.

The system sum-rate is formulated as

$$U(\boldsymbol{\nu},\mathbf{P})=\sum_{f\in\mathcal{F}}\sum_{s\in\mathcal{S}_f}\sum_{n\in\mathcal{N}}r^f_{s,n}, \tag{1}$$

where $r^f_{s,n}$ is the rate that user s can achieved from subcarrier n over BS f which is attained as

$$r^f_{s,n}=\log(1+\gamma^f_{s,n}), \tag{2}$$

where $\gamma^f_{s,n}$ is the SINR of user s in sub-carrier n over BS f and is obtained by

$$\gamma^f_{s,n}=\frac{\nu^f_{s,n}p^f_{s,n}|h^f_{s,n}|^2}{|h^f_{s,n}|^2\sum_{j=1}^{s-1}\nu^f_{j,n}p^f_{j,n}+I^f_{s,n}+N_0}, \tag{3}$$

where $I^f_{s,n}$ is the intercell interference and is achieved by

$$I^f_{s,n}=\sum_{f\in\mathcal{F}/\{f\}}\sum_{s\in\mathcal{S}_f}p^f_{k,n}|h^f_{k,n}|^2. \tag{4}$$

Also, the total power consumption in the system is given by

$$U_{TP}(\boldsymbol{\nu},\mathbf{P})=P_c+\sum_{f\in\mathcal{F}}\sum_{n\in\mathcal{N}}\sum_{s\in\mathcal{S}_f}\nu^f_{s,n}p^f_{s,n}, \tag{5}$$

where, P_c is the power dissipation of devices and electronic circuits, and the second term is total power which consumed in the power amplifier. The EE of the considered cellular system is defined as the system sum-rate per unit energy consumption which is achieved by

$$U=\frac{U(\boldsymbol{\nu},\mathbf{P})}{U_{TP}(\boldsymbol{\nu},\mathbf{P})}.$$

Finally, our problem formulation of maximizing system EE is expressed as

$$\max_{\boldsymbol{\nu},\mathbf{P}}\ \frac{U(\boldsymbol{\nu},\mathbf{P})}{U_{TP}(\boldsymbol{\nu},\mathbf{P})}, \tag{6a}$$

$$\text{s.t.}:\ \sum_{n\in\mathcal{N}}\sum_{s\in\mathcal{S}_f}\nu^f_{s,n}p^f_{s,n}\le P^f_{\max},\ \ \forall f\in\mathcal{F}, \tag{6b}$$

$$\sum_{i=1}^{s-1}\nu^f_{i,n}\sqrt{p^f_{i,n}}\le\nu^f_{s,n}\sqrt{p^f_{s,n}}\ \ ,\forall s\in\mathcal{S}_f,n\in\mathcal{N},f\in\mathcal{F}, \tag{6c}$$

$$\sum_{n\in\mathcal{N}}\sum_{f\in\mathcal{F}}\nu^f_{s,n}r^f_{s,n}\ge R^m_{\min},\ \ s\in\mathcal{S}_f, \tag{6d}$$

$$\sum_{s\in\mathcal{S}_f}\nu^f_{s,n}\le L_T,\ \ \forall n\in\mathcal{N},f\in\mathcal{F}, \tag{6e}$$

$$p^f_{s,n}\ge 0,\forall s\in\mathcal{S}_f,n\in\mathcal{N},f\in\mathcal{F}, \tag{6f}$$

$$\nu^f_{s,n}\in\{0,1\},\ \ \forall s\in\mathcal{S}_f,n\in\mathcal{N},f\in\mathcal{F}, \tag{6g}$$

where (6b) indicates the limitation on maximum available power in each BS, (6c) shows the NOMA constraint, (6d) denotes the minimum rate requirement for each users and (6e) shows that each subcarrier can be assigned to at most L_T users simultaneously.

Problem (6) is a mixed combinatorial and non-convex optimization problem. The non-convexity comes from the objective function and constraint (6d), and combinatorial comes from the existence of integer variable $\boldsymbol{\nu}$ which indicates the subcarrier allocation notation. To solve the proposed problem an iterative algorithm is exploited which in each iteration power and subcarrier are allocated separately, it means that to allocate power, the subcarrier parameters are supposed fixed and to allocate subcarrier, the power parameters are assumed fixed. This iterative method is continued until convergence. Moreover, the objective function is in the fractional form and the function of system sum-rate because of existence the interference is non-convex. To handle the first issue the fractional programing theory is used and to tackle the non-convexity issue the SCA approach is applied.

III. SOLUTION OF THE OPTIMIZATION PROBLEM

In the first step of the solution, the fractional programing theory is used to change the objective function with equivalent objective function in subtractive form, then the iterative method based on SCA approach is used.

A. Transformation of the Objective Function

We define Q^* as the maximum system EE which is achieved by

$$\frac{U(\boldsymbol{\nu}^*, \mathbf{P}^*)}{U_{TP}(\boldsymbol{\nu}^*, \mathbf{P}^*)} = \max_{\boldsymbol{\nu}, \mathbf{P}} \frac{U(\boldsymbol{\nu}, \mathbf{P})}{U_{TP}(\boldsymbol{\nu}, \mathbf{P})} = Q^*, \tag{7}$$

where $\boldsymbol{\nu}^*, \mathbf{P}^*$ are the matrix of optimal power and subcarrier allocation.

We use the following Theorem which is related to nonlinear fractional programming [15].

Theorem 1. *The maximum energy efficiency Q^* is achieved if and only if*

$$\max_{\boldsymbol{\nu}, \mathbf{P}} U(\boldsymbol{\nu}, \mathbf{P}) - Q^* U_{TP}(\boldsymbol{\nu}, \mathbf{P}) = U(\boldsymbol{\nu}^*, \mathbf{P}^*) - Q^* U_{TP}(\boldsymbol{\nu}^*, \mathbf{P}^*) = 0, \tag{8}$$

for $U(\boldsymbol{\nu}, \mathbf{P}) \geq 0$ and $U_{TP}(\boldsymbol{\nu}, \mathbf{P}) > 0$.

Proof. Please see [7] for proof of considered theorem. □

By applying Theorem 1, the objective function of any problems in fractional form can be written with an objective function in subtractive form, e.g. $U(\boldsymbol{\nu}, \mathbf{P})/U_{TP}(\boldsymbol{\nu}, \mathbf{P})$ is written by $U(\boldsymbol{\nu}, \mathbf{P}) - Q^* U_{TP}(\boldsymbol{\nu}, \mathbf{P})$. The new problem formulation is equivalent to primary problem and both of them have the same policy to resource allocation. Consequently, we focus on the solution of the following resource allocation problem

$$\max_{\boldsymbol{\nu}, \mathbf{P}} U(\boldsymbol{\nu}, \mathbf{P}) - Q U_{TP}(\boldsymbol{\nu}, \mathbf{P}), \tag{9}$$
$$\text{s.t.}: \quad (6\text{b}) - (6\text{g}).$$

B. Main resource allocation algorithm

To solve problem (9), an iterative algorithm is used. An overview of the proposed algorithm is shown in Table 1. The algorithm is started by initialization $Q = 0$, then, in step $3 - a$, by solving (9), $\mathbf{P}$ and $\boldsymbol{\nu}$ are obtained, in step $3 - b$, stop condition is checked, if the condition is satisfied by calculated power and subcarrier, they are considered as the optimal values, otherwise, Q is updated and the algorithm is continued until convergence. Out put of the Table 1 is the optimal power and subcarrier allocation which achieve the maximum system EE.

C. Solution of the resource allocation with constant Q

To solve problem (9) an iterative algorithm based on SCA approach is applied. In each iteration power and subcarrier are allocated separately and the iterative algorithm is continued until convergence. An overview of this iterative approach is presented in Table 2. The algorithm is started by initialization the power and subcarrier matrices, then power and subcarrier are allocated separately. The power allocation problem is non-convex, therefore, to solve it an SCA approach is used and the subcarrier allocation is MINLP which can be solved by applying available software for MINLP.

Algorithm 1 ITERATIVE RESOURCE ALLOCATION

1: Initialization: Initialize $M_{\max}$ (maximum iteration number), the maximum tolerance ϵ, $Q = 0$, and set $m = 0$ (as the iteration number).
2: Repeat:
3-a: Solve the problem 9 for a given Q and obtain power and subcarrier as $\{\boldsymbol{\nu}', \mathbf{P}'\}$.
3-b: When $U(\boldsymbol{\nu}', \mathbf{P}') - Q U_{TP}(\boldsymbol{\nu}', \mathbf{P}) < \epsilon$ or $m = M_{\text{mnax}}$, stop and return $\{\boldsymbol{\nu}, \mathbf{P}\} = \{\boldsymbol{\nu}', \mathbf{P}'\}$ and $Q^* = Q$.
Otherwise,
Set $Q = \dfrac{U(\boldsymbol{\nu}', \mathbf{P}')}{U_{TP}(\boldsymbol{\nu}', \mathbf{P})}$, $m = m + 1$ and go back to $3 - a$.
Output: $\{\boldsymbol{\nu}', \mathbf{P}'\}$ as optimal power and subcarrier, and $Q = Q^*$ as the maximum system EE.

Algorithm 2 ITERATIVE RESOURCE ALLOCATION TO SOLVE THE EQUIVALENT PROBLEM

1: Initialization: Set $k = 0$ (as the iteration number), initialize K (maximum iteration number), find $\boldsymbol{\nu}(0)$ and $\mathbf{P}(0)$ by applying described initialization method.
2: Repeat:
2-a: Set $\boldsymbol{\nu} = \boldsymbol{\nu}(k)$ and find a solution of problem (9) consider it as $\mathbf{P}(k+1)$,
2-b: Find $\boldsymbol{\nu}(k+1)$ by solving (9) and considering $\mathbf{P} = \mathbf{P}(k+1)$,
2-c: When $|\mathbf{P}(k) - \mathbf{P}(k-1)| \leq \epsilon$ or $k = K$, stop.
Otherwise, set $k = k + 1$ and go back to 2-a.
Output: Matrices $\boldsymbol{\nu}$ and $\mathbf{P}$ as a solution of power and subcarrier.

D. Initialization Method

The algorithm of finding feasible initialization matrices for sub-carrier and power are summarized in Algorithm 3 [16], [17].

Algorithm 3 INITIALIZATION METHOD

COMPUTING $\mathbf{P}(0)$:
Soppuse SBSs are not transmitting, then for MBS users solve the convex problem of finding $\mathbf{P}(0)$ (problem (9) without rate requirement constraint and interference).
FINDING $\boldsymbol{\nu}(0)$:
Subcarriers are assigned to MBS user which has the highest SINR.

E. Sub-carrier Allocation with Fixed Power

The subcarrier allocation problem with fixed power is formulated as

$$\max_{\boldsymbol{\nu}} U(\boldsymbol{\nu}, \mathbf{P}) - Q U_{TP}(\boldsymbol{\nu}, \mathbf{P}), \tag{10}$$
$$\text{s.t.}: \quad (6\text{b}) - (6\text{e}),\ (6\text{g}).$$

This problem is in MINLP form and is solved by opti-toolbox.

F. Power Allocation with Fixed Sub-carrier Allocation

By considering $\boldsymbol{\nu} = \boldsymbol{\nu}(s)$, the power allocation problem is expressed as

$$\max_{\mathbf{P}} U(\boldsymbol{\nu}, \mathbf{P}) - QU_{TP}(\mathbf{P}), \tag{11}$$
$$\text{s.t.}: \quad (6b) - (6d), \ (6f).$$

To solve this problem a SCA approach, namely, successive convex approximation with low complexity (SCALE) is applied. The SCALE method approximates the non-convex rate function with a convex one by using the following inequality [18],

$$\eta \log(w) + \xi \leq \log(1 + w), \tag{12}$$

where

$$\eta = \frac{\mathcal{W}_0}{\mathcal{W}_0 + 1}, \ \xi = \log(1 + \mathcal{W}_0) - \frac{\mathcal{W}_0}{\mathcal{W}_0 + 1} \log(\mathcal{W}_0). \tag{13}$$

By applying (13) the power allocation problem is written as

$$\max_{\boldsymbol{\nu},\mathbf{P}} \sum_{f\in\mathcal{F}} \sum_{s\in\mathcal{S}_f} \sum_{n\in\mathcal{N}} \rho^f_{s,n} (\eta^f_{s,n} \log(\gamma^f_{s,n}) + \xi^f_{s,n}) - QU_{TP}(\boldsymbol{\nu}, \mathbf{P}), \tag{14a}$$

$$\text{s.t.}: \quad \sum_{n\in\mathcal{N}} \sum_{s\in\mathcal{S}_f} \rho^f_{s,n} p^f_{s,n} \leq P^f_{\text{max}}, \ \ \forall f \in \mathcal{F}, \tag{14b}$$

$$\sum_{i=1}^{m-1} \rho^f_{i,n} \sqrt{p^f_{i,n}} \leq \rho^f_{s,n} \sqrt{p^f_{s,n}} \ \ , \forall s \in \mathcal{S}_f, n \in \mathcal{N}, f \in \mathcal{F}, \tag{14c}$$

$$\sum_{n\in\mathcal{N}} \sum_{f\in\mathcal{F}} \rho^f_{s,n} (\eta^f_{s,n} \log(\gamma^f_{s,n}) + \xi^f_{s,n}) \geq R^s_{\text{min}}, \ \ \forall s \in \mathcal{S}_f, \tag{14d}$$

$$p^f_{s,n} \geq 0, \forall s \in \mathcal{S}_f, n \in \mathcal{N}, f \in \mathcal{F}. \tag{14e}$$

To achieve appropriate approximation, an iterative algorithm is applied which is shown in Algorithm 4. Problem (14) is still non-convex. By transformation $p^f_{s,n} = \exp(\tilde{p}^f_{s,n})$, a standard form of concave maximization problem in the new variables $\tilde{\boldsymbol{P}}$ is achieved. To solve the convex optimization problem dual method is applied, hence, the dual function is formulated as

$$\begin{aligned} L(\boldsymbol{\beta}, \boldsymbol{\delta}, \boldsymbol{\lambda}, \exp \tilde{\mathbf{p}}) &= \sum_{f\in\mathcal{F}} \sum_{s\in\mathcal{S}_f} \sum_{n\in\mathcal{N}} \rho^f_{s,n} (\eta^f_{s,n} \log(\gamma^f_{s,n}) + \xi^f_{s,n}) \\ &- QU_{TP}(\mathbf{P}) + \sum_{f\in\mathcal{F}} \beta_f (\sum_{n\in\mathcal{N}} \sum_{s\in\mathcal{S}_f} \rho^f_{s,n} \exp \tilde{p}^f_{s,n} - P^f_{\text{max}}) \\ &+ \sum_{f\in\mathcal{F}} \sum_{s\in\mathcal{S}_f} \sum_{n\in\mathcal{N}} \delta^f_{s,n} (\sum_{i=1}^{m-1} \rho^f_{i,n} \sqrt{\exp \tilde{p}^f_{i,n}} - \rho^f_{s,n} \sqrt{\exp \tilde{p}^f_{s,n}}) \\ &- \sum_{s\in\mathcal{S}_f} \lambda_s (\sum_{f\in\mathcal{F}} \sum_{n\in\mathcal{N}} \rho^f_{s,n} (\eta^f_{s,n} \log(\gamma^f_{s,n}) + \xi^f_{s,n}) - R^m_{\text{min}}) \end{aligned} \tag{15}$$

where $\boldsymbol{\beta}, \boldsymbol{\lambda}$ and $\boldsymbol{\delta}$ are non-negative Lagrange multipliers. To solve the dual maximization problem, we should find the stationary point of (15)

$$\frac{d(L(\boldsymbol{\beta}, \boldsymbol{\delta}, \boldsymbol{\lambda}, \tilde{\mathbf{P}}))}{d\tilde{p}^f_{s,n}} = 0. \tag{16}$$

Then, after simplifying (16), and transformation $\ln(p^f_{s,n}) = \hat{p}^f_{s,n}$, $p^f_{s,n}$ is obtained as (17) where p_{masq} indicates the maximum power wich can be assigned to each user in a subcarrier . We update the dual variables through sub-gradient method as

$$\beta^{t+1}_f = \left[\beta^t_f + o_1 \left(\sum_{n\in\mathcal{N}} \sum_{s\in\mathcal{S}_f} \nu^f_{s,n} p^f_{s,n} - P^f_{\text{max}} \right) \right]^+, \tag{18}$$

$$\lambda^{t+1}_s = \left[\lambda^t_s - o_2 \left(\sum_{f\in\mathcal{F}} \sum_{n\in\mathcal{N}} \nu^f_{s,n} r^f_{s,n} - R^m_{\text{min}} \right) \right]^+,$$

$$\delta^f_{s,n}(t+1) = \left[\delta^f_{s,n}(t) + o_3 \left(\sum_{i=1}^{s-1} \nu^f_{i,n} \sqrt{p^f_{i,n}} - \nu^f_{s,n} \sqrt{p^f_{s,n}} \right) \right]^+,$$

where $[\Omega]^+ = \max(\Omega, 0)$, and o_1, o_2 and o_3 are sufficiently small step-size for updating Lagrange multipliers. The algorithm to find stationary point is shown in Algorithm (5).

Algorithm 4 Algorithm to improve SCA approach

1: Initialization: Set $z = 0$ (as the iteration number), initialize Z_{max} (as the maximum iteration number) and $\boldsymbol{\xi} = 0$ and $\boldsymbol{\eta} = 1$,
2: Repeat:
2-a: Compute $\mathbf{P}(z)$ by solving (14),
2-b: Update $\boldsymbol{\xi}$ and $\boldsymbol{\eta}$ with $\mathcal{W}_0 = \gamma^f_{s,n}(\mathbf{P}(z))$,
2-c: When $z = Z_{\text{max}}$ stop.
otherwise, set $z = z + 1$ and go back to 2-a.

Algorithm 5 AlGORITHM TO FIND STATIONARY POINT

1: Initialization: Set $t = 0$ (as the iteration number), compute $\boldsymbol{\lambda}(0)$, $\boldsymbol{\beta}(0)$ and $\boldsymbol{\delta}^f_{s,n}(0)$,
2: Repeat:
2-a: Compute $\mathbf{P}$ by using (17),
2-b: Update $\boldsymbol{\lambda}$, $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$ by applying (18)
2-c: When $|\delta^t - \delta^{t-1}| \leq \epsilon$, $|\lambda^t - \lambda^{t-1}| \leq \epsilon$ and $|\beta^t - \beta^{t-1}| \leq \epsilon$ stop.
Otherwise, set $t = t + 1$ and go back to 2-a.

- **Convergence Discussion**
  According to [20], by converging the sequence of iterations, the feasible solution which satisfied the KKT optimality conditions of the original non-convex problem is obtained, i.e., with SCALE, the SCA approach by generating the sequence of improved solution converges to a locally optimal. Convergence of SCALE can be easily obtained by following the same line of argument as in [20].

IV. COMPUTATIONAL COMPLEXITY

To investigate computational complexity of our resource allocation method, we consider it as to steps, 1: subcarrier allocation, 2: power allocation. To solve subcarrier allocation

$$p^f_{s,n} = \left[\frac{(1+\lambda_m)\eta^f_{s,n} + \frac{1}{2\sqrt{p^f_{s,n}}}(\delta^f_{s,n} - \sum_{i=s+1}^{S_f} \rho^f_{i,n}\delta^f_{i,n})}{\sum_{i=s+1}^{s_f}(1+\lambda_i)\eta^f_{i,n}\frac{\gamma^f_{i,n}}{p^f_{i,n}} - Q + \beta_f + \sum_{j\in\mathcal{F}/\{f\}}\sum_{s\in\mathcal{S}_f}\eta^j_{s,n}\frac{|h^f_{s,n}|^2\gamma^j_{s,n}}{|h^j_{s,n}|^2 p^j_{s,n}}} \right]^{\text{mask}}. \tag{17}$$

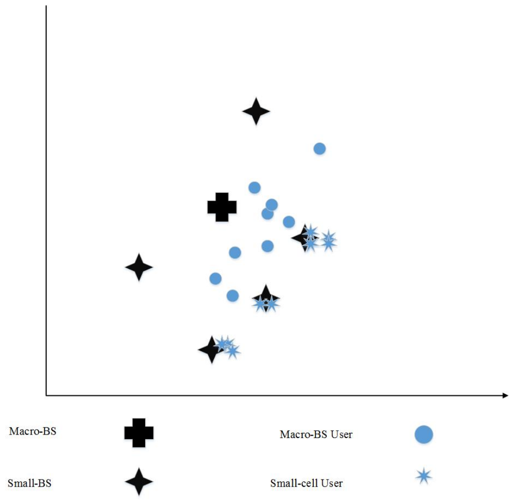

Fig. 2: A typical user placement.

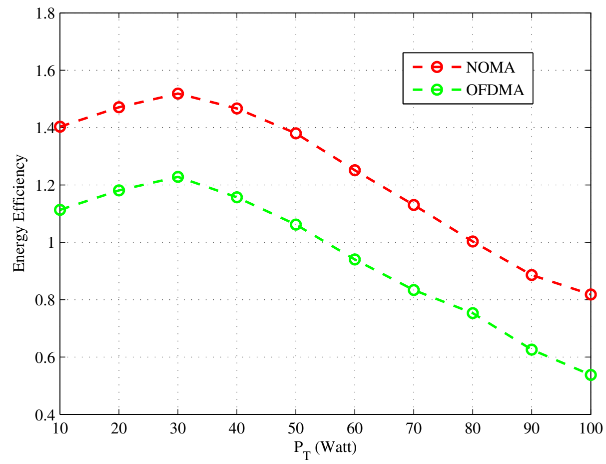

Fig. 3: Energy efficiency versus total available power.

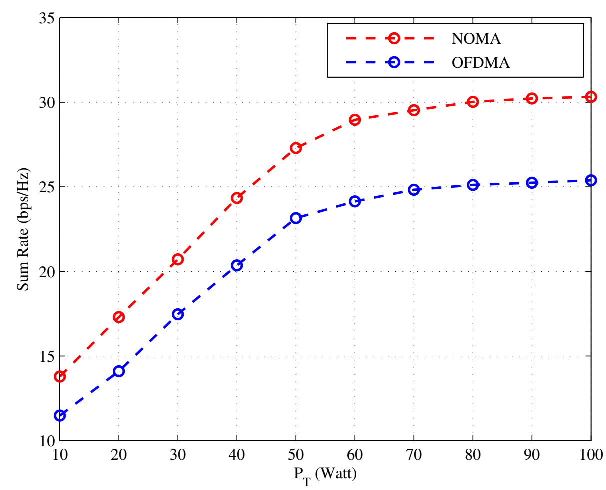

Fig. 4: System sum-rate versus total available power.

problem by opti-toolbox geometric programing with the interior point approach is used, which it's computation complexity is achieved by

$$\mathcal{O}(\frac{\log(\frac{C}{t_0\xi})}{\log(\nu_0)}), \tag{19}$$

where C is the number of all constraints in the subcarrier allocation problem, and $0 < \nu_0 \ll 1$, t_0 and ξ are the parameters of interior point method, which are the stopping criterion, initial point for approximated the accuracy and the parameter to update the accuracy respectively [21].

Power allocation by applying SCALE method contains two steps, 1: calculate the users power with (16) and updating the dual variables. The complexity of first step is attained by $\mathcal{O}(M \times S \times N)$ and for the second step is achieved by $\mathcal{O}(F + S + M \times S \times N)$ [17].

V. Simulation Results

In this section, simulation results on the sum-rate and EE are presented to show the performance of proposed resource allocation algorithm. A typical user placement and network topology is shown in Fig. 2. The parameters are supposed as: $N = 32$ (the number of sub-carrier), $L_T = 3$ (maximum number of users which a sub-carrier can be assigned to them sub-carrier), $S_f = 4 \forall f \in \mathcal{F}/\{1\}$, $S_1 = 12$, $p^0_{\max} = 40(Watt)$, $p^f_{\max} = 4(Watt) \forall f \in \mathcal{F}/\{1\}$, $D = .5Km$ (radius of MBS) and $d = 25m$ (radius of SBS). The channel gain of user s on sub-carrier n in BS f is considered as $h^f_{s,n} = \nu'^f_{s,n}(d)^{-2}$ where $\nu'^f_{s,n}$ is an exponential random variable which representing the Rayleigh fading EE and system sum-rate which can be achieved by NOMA-based system are compared to OMA-based system. Fig. 3 and Fig. 4, respectively show the EE and system sum-rate versus the total transmit power for NOMA-based and OMA-based system. As can be seen NOMA-based system achieves better system performance than OMA-based system in terms of system sum-rate and EE.

VI. Conclusion

In this paper, we proposed a resource allocation method to achieve appropriate system EE for NOMA-based HCN systems. The proposed resource allocation problem was non-convex and contains both integer and continuous variables, therefore, to solve it we used an iterative algorithm based on fractional programing and SCA approach. Also, we investigated about the computational complexity of proposed resource allocation method. As the numerical results show, the system EE in NOMA-based systems outperforms the EE of OMA-based systems at the cost of increasing system complexity.

REFERENCES

[1] M. Pickavet, W. Vereecken, S. Demeyer, P. Audenaert, B. Vermeulen, C. Develder, D. Colle, B. Dhoedt, and P. Demeester, "Worldwide energy needs for ICT: The rise of power-aware networking," *in Proc. IEEE ANTS, Mumbai*, pp. 13, Dec. 2008.

[2] Qualcomm, Rising to Meet the 1000x Mobile Data Challenge, Qualcomm, 2012.

[3] S. Wang, M. Ge, and W. Zhao, "Energy-efficient resource allocation for OFDM-based cognitive radio networks," *IEEE Trans. Commun.*, vol. 61, no. 8, pp. 3181-3191, Aug. 2013.

[4] X. Sun and S. Wang,"Resource allocation scheme for energy saving in heterogeneous networks." *IEEE Trans. Wireless Commun.*, vol. 14, no. 8, pp. 4407-4416, Aug. 2015.

[5] D. Cao, S. Zhou, and Z. Niu,"Optimal combination of base station densities for energy-efficient two-tier heterogeneous cellular networks," *IEEE Trans. Wireless Commun.*, vol. 12, no. 9, pp. 4350-4362, Sep. 2013.

[6] Y. B. Lin, T. H. Chiu and Y. T. Su, "Optimal and near-Optimal resource allocation algorithms for OF-DMA networks," *IEEE Trans. Wireless commun.*, Vol. 8, no. 8, pp. 4066-4077, Aug. 2009.

[7] D. W. K. Ng, E. S. Lo and R. Schober,"Energy-efficient resource allocation in multiuser OFDM systems with wireless information and power transfer," *in Proc. IEEE WCNC, , Shanghai.*, pp. 3823-3828, Apr. 2013.

[8] Z. Niu, "Tango: traffic-aware network planning and green operation," *IEEE Trans. Wireless Commun.*, vol. 18, no. 5, pp. 25-29, 2011.

[9] K. Son, H. Kim, Y. Yi, and B. Krishnamachari,"Base station operation and user association mechanisms for energy-delay tradeoffs in green cellular networks," *IEEE J. Sel. Areas Commun.*, vol. 29, no. 8, pp. 1525-1536, Sep. 2011.

[10] Tse, D.: "Optimal power allocation over parallel gaussian broadcast channels". *in Proc. IEEE ISIT, Ulm.,* Jul. 1997.

[11] L. Li and A. J. Goldsmith, "Capacity and optimal resource allocation for fading broadcast channels .l. Ergodic capacity", *IEEE Trans. Inf. Theory,* vol. 47, no. 3, pp. 1083-1102, Mar 2001.

[12] Y. Saito, A. Benjebbour, Y. Kishiyama, and T. Nakamura, "Systemlevel performance evaluation of downlink non-orthogonal multiple access (NOMA)," *in proc. IEEE PIMRC, London.*, pp. 611-615, Sep. 2013.

[13] p. xu, Z. Ding, x dai, and H. V. Poor, "A new evaluation criterion for non-Orthogonal multiple access in 5G software defined networks," *IEEE Access.*, vol. 3, pp. 1633-1639, Oct 2015.

[14] A. Mokdad, P. Azmi, and N. Mokari, "Radio resource allocation for heterogeneous traffic in GFDM-NOMA heterogeneous cellular networks," *Accepted IET communications.*

[15] W. Dinkelbach, "On nonlinear fractional programming," Management Science, vol. 13, pp. 492-498, Mar. 1967. [Online]. Available: http://www.jstor.org/stable/2627691.

[16] Trong Ngo, D., Khakurel, S., Le-Ngoc, T.: "Joint subchannel assignment and power allocation for OFDMA femtocell networks", *IEEE Trans. Wireless Commun.*, pp, 2014. 342-355.

[17] Mokari, N., Alavi, F., Parsaeefard, S. et al.: "Limited-Feedback Resource Allocation in Heterogeneous Wireless Networks", *accepted in IEEE Trans. Veh. Technol.*, 2015, (99

[18] J. Papandriopoulos and J. S. Evans, "SCALE: A low-complexity distributed protocol for spectrum balancing in multiuser dsl networks," *IEEE Trans. Inf. Theory.*, vol. 55, no. 8, p. 3711-3724, Aug. 2009.

[19] Trong Ngo, D., Khakurel, S., Le-Ngoc, T.: "Joint subchannel assignment and power allocation for OFDMA femtocell networks", *IEEE Trans. Wireless Commun.*,vol. 13, no. 1, pp. 342-355, Jan. 2014.

[20] K. Son, S. Lee, Y. Yi, and S. Chong, "REFIM: A practical interference management in heterogeneous wireless access networks," *IEEE J. Sel. Areas Commun.*, vol. 29, no. 6, pp. 1260-1272, Jun. 2011.

[21] S. Boyd and L. Vandenberghe, *Convex Optimization*. Cambridge Univ. Press, 2004.