2019 IEEE International Conference on Consumer Electronics - Taiwan (ICCE-TW)

# Energy-Efficient Transmission Design for Downlink Non-Orthogonal Multiple Access Network

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***Abstract*—In order to improve the energy efficiency (EE) of non-orthogonal multiple access (NOMA) network, this paper focuses on energy-efficient transmission design for downlink NOMA network by reasonable resource allocation. We first study the power allocation on multiple users in each cluster and obtain the optimal closed-form solution of the power allocation coefficient. Then, a novel power allocation strategy across clusters is proposed to further maximize the total EE. Since the original optimization problem is non-convex, a successive convex approximation (SCA) method is introduced to find a sub-optimal solution of the non-convex one. Numerical results indicate that NOMA performs well than orthogonal multiple access (OMA) in terms of total EE and our proposed power allocation algorithm significantly outperforms the equal power allocation strategy.**

***Index Terms*—Energy efficiency, non-orthogonal multiple access, successive convex approximation, power allocation.**

## I. Introduction

In recent years, non-orthogonal multiple access (NOMA) has been investigated as one of the key radio access technology for 5G networks [1]. Since that multiple users can be multiplexed on the same cluster in NOMA network which can significantly improve system spectral efficiency (SE), early research on NOMA focused mostly on SE. Alongside, energy efficiency (EE) has drawn more and more attention now because the information and communication technology accounts for a considerable amount of total world energy consumption. In [2], the downlink EE resource allocation algorithm for NOMA network has been investigated. The authors put forward a Dinkelbach-like algorithm to determine the sub-optimal solution. In addition, in [3], the difference of convex programming (DCP) is utilized to handle the total EE maximization problem for downlink NOMA. However, the above two algorithms are both of high computational complexity. Research on power allocation algorithms for downlink NOMA network needs to go further.

Motivated by the above work, this paper firstly derives a more general expression of the optimal power allocation coefficients among cluster multiplexed users. Then, a successive convex approximation (SCA) method is utilized to significantly reduce the complexity of the resource allocation algorithm for downlink NOMA network.

## II. System Model And Problem Formulation

### A. System Model

In this paper, a downlink NOMA network is considered, in which both the base station (BS) and users are equipped with single antenna. And a BS transmits its signals to $N \times L$ users between $N$ clusters. In the cell, $N\times L$ users are uniformly distributed in a circular region with radius $R$, and random pairing is used for user clustering. The channel from the BS to the $l$th user in the $n$th cluster ($C_n$), i.e., $1\le l\le L$, $1\le n\le N$, is modeled as $h_{n,l} = g_{n,l} d_{n,l}^{-\beta/2}$, where $g_{n,l}$ is the Rayleigh fading coefficient, $d_{n,l}$ is the distance between the BS and the $l$th user in $C_n$, and $\beta$ is the path-loss exponent. In NOMA systems, we assume that the BS has full knowledge of the channel state information (CSI). Without loss of generality, we assume that $0 \le |h_{n,1}|^2 \le |h_{n,2}|^2 \le \cdots \le |h_{n,L}|^2$.

According to the NOMA protocol, at the receiver, successive interference cancelation (SIC) is conducted. The $l$th user first decodes the $k$th user's message, i.e., $k < l$, and then removes this message from its received signal. The messages for the $k$th user, i.e., $k > l$, are treated as noise [4]. Thus, the achievable rate of the $l$th user in $C_n$ can be given by

$$R_{n,l}(P_{n,l}) = \log_2\left(1+\frac{|h_{n,l}|^2 P_{n,l}}{|h_{n,l}|^2 \sum_{k=l+1}^{L} P_{n,k} + \sigma^2}\right), \tag{1}$$

where $P_{n,l}$ is the power allocated to the $l$th user in $C_n$ and $\sigma^2$ is the power of the noise. The sum rate of $C_n$ is denoted by

$$R_n(P_n) = \sum_{l=1}^{L} R_{n,l}(P_{n,l}). \tag{2}$$

The EE over $C_n$ is defined as

$$EE_n = \frac{R_n(P_n)}{P_n + P_c}, \tag{3}$$

where $P_n$ is the power assigned to $C_n$, $P_c$ is the constant which presents the circuit power consumption.

### B. Problem Formulation

In this subsection, we formulate resource allocation as an EE optimization problem. Specially, for the purpose of reducing the complexity of the SIC receiver and restrict the error propagation, we assume that only two users are assigned to each cluster at the same time. In this case, considering that the two users share $C_n$ with $|h_{n,1}|^2 \le |h_{n,2}|^2$, then the sum rate of $C_n$ can be given by

$$R_n(P_n) = \log_2\left(1+\frac{|h_{n,1}|^2 P_n(1-\alpha_n)}{|h_{n,1}|^2 P_n\alpha_n + \sigma^2}\right) + \log_2\left(1+\frac{|h_{n,2}|^2 P_n\alpha_n}{\sigma^2}\right), \tag{4}$$

where $\alpha_n$ is the power proportional factor assigned to the user who performs SIC in $C_n$, i.e., $P_{n,1}=(1-\alpha_n)P_n$ and $P_{n,2}=\alpha_n P_n$. To make sure that the weak user's power ($U_1$) is larger than that of strong user ($U_2$), we may set $\alpha_n < 0.5$.

This paper is aiming at maximizing the total system EE in the NOMA system. Then, the total EE optimization problem is formulated as

$$\max_{P_n>0} \sum_{n=1}^{N} \frac{R_n(P_n)}{P_c + P_n} \tag{5a}$$

$$s.t.\ \ R_{n,l} \ge R_{\min} \tag{5b}$$

$$\sum_{n=1}^{N} P_n \le P_{tot}. \tag{5c}$$

This work was partly supported by the National Natural Science Foundation of China under Grant 61372124 and Grant 61427801, partly supported by the National Key Research and Development Program of China under Grant 2018YFC1314903.

where constraint (5b) denotes the minimum data rate requirements of the users in the system and constraint (5c) guarantees the maximum transmit power constraint at the BS. In this paper, we assume that all of the users share the same minimum data rate requirement $R_{\min}$.

## III. Energy-Efficient Power Allocation Algorithm

### *A. Power Allocation Between The Two Users on Each Cluster*

This subsection formulates the power allocation problem between the two users in each cluster and try to find the optimal power allocation coefficient $\alpha_n^*$ between the two users, and then we rewrite the EE expression over $C_n$ as

$$EE_n = \frac{\log_2\left(\frac{|h_{n,1}|^2 P_n + \sigma^2}{\sigma^2}\right) + \log_2\left(\frac{|h_{n,2}|^2 P_n\alpha_n + \sigma^2}{|h_{n,1}|^2 P_n\alpha_n + \sigma^2}\right)}{P_n + P_c}. \quad (6)$$

For any given transmit power $P_n$, maximizing EE over the $n$th cluster is equivalent to maximize the function $H(\alpha_n)$, where $H(\alpha_n) = \frac{|h_{n,2}|^2 P_n\alpha_n + \sigma^2}{|h_{n,1}|^2 P_n\alpha_n + \sigma^2}$. Since $\frac{dH(\alpha_n)}{d\alpha_n} > 0$, maximizing $H(\alpha_n)$ is equivalent to maximize $\alpha_n$ with constraints that $R_{n,1} \geq R_{\min}$ and $R_{n,2} \geq R_{\min}$. Solving the optimization problem above, we can obtain the optimal solution:

$$\alpha_n^* = \frac{1}{A+1} - \frac{A\sigma^2}{(A+1)|h_{n,1}|^2 P_n}, \quad (7)$$

where $A = 2^{R_{\min}} - 1$.

### *B. Energy Efficient Power Allocation Across Clusters*

This subsection studies the energy-efficient power allocation across clusters. First, we substitute $\alpha_n^*$ into (4), (5a) can be recast to $\max_{P_n} \sum_{n=1}^{N} F(P_n)$ with the same constraint, where

$$F(P_n) = \frac{R_{\min}}{P_n + P_c} + \frac{\log_2\left(1 + \frac{|h_{n,1}|^2|h_{n,2}|^2 P_n - A|h_{n,2}|^2\sigma^2}{(A+1)|h_{n,1}|^2\sigma^2}\right)}{P_n + P_c}. \quad (8)$$

Then, we use a novel SCA method to transform nonconvex optimization problems into convex optimization problems. We make use of the following lower bound on the logarithmic function to finish the approximation:
$\ln(1+x)/t \geq a - b/x - ct$, where $a = 2\ln(1+\bar{x})/\bar{t} + \bar{x}/(\bar{t}(\bar{x}+1))$, $b = \bar{x}^2/(\bar{t}(\bar{x}+1))$, $c = \ln(1+\bar{x})/\bar{t}^2$, and $a$, $b$, $c$>0. By Setting $x_{n,1} = 2^{R_{\min}} - 1$, $x_{n,2} = \frac{|h_{n,1}|^2|h_{n,2}|^2 P_n - A|h_{n,2}|^2\sigma^2}{(A+1)|h_{n,1}|^2\sigma^2}$, $t = P_n + P_c$, the original optimization problems can be reformulated to $\max_{P_n} G(P_n)$ with constraint (5b) and (5c), where

$$G(P_n) = \sum_{n=1}^{N}\left(a_{n,1} - \frac{b_{n,1}}{x_{n,1}} - c_{n,1}t + a_{n,2} - \frac{b_{n,2}}{x_{n,2}} - c_{n,2}t\right). \quad (9)$$

Since $G(P_n)$ is strictly concave, then we use the following Algorithm 1 to obtain a feasible solution to the original problem.

## IV. Simulation Results And Discussion

In this section, we analyze the proposed energy-efficient power allocation algorithm numerically, which is labeled as "NOMA-SCA", and the equal power allocation schemes are labeled as "NOMA-EQ" and "OMA-EQ". The system parameters are set as: $\alpha = 3$, $\sigma^2 = -70$ dBm, $R_{\min} = 2$ bit/s/Hz, $P_c = 30$ dBm, and $\varepsilon = 0.001$.

We first show the convergence of the Algorithm 1 with $P_{\text{tot}} = 5$ W. As can be seen from Fig. 1, Algorithm 1 has a fast convergence speed, and it reaches the optimal solution within about 8 iterations. Fig. 2 plots the total EE versus BS power with 10 users. It indicates that there exists a "Green Point" at which the maximum EE is achieved by all three strategies. The EE performance of the proposed "NOMA-SCA" algorithm is superior than that of both "NOMA-EQ" and "OMA-EQ" schemes.

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**Algorithm 1:** Energy-efficient power allocation across cluster by NOMA-SCA

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**1**: Initialize $\varepsilon$, $l$=0, $\{P_n^{(0)}\}_{n=1}^{N}$;

**2**: Set $\bar{x}_{n,1} = x_{n,1}(\{P_n^{(0)}\}_{n=1}^{N})$, $\bar{x}_{n,2} = x_{n,2}(\{P_n^{(0)}\}_{n=1}^{N})$, $\bar{t} = t(\{P_n^{(0)}\}_{n=1}^{N})$ and calculate $a_{n,1}$, $b_{n,1}$, $c_{n,1}$, $a_{n,2}$, $b_{n,2}$, $c_{n,2}$;

**3**: Solve convex problem $G(P_n)$, $\{P_n^*\}_{n=1}^{N} = \arg\max_{P_n} G(P_n)$;

**4**: **while** $|\sum_{n=1}^{N} F(\{P_n^{(0)}\}_{n=1}^{N}) - \sum_{n=1}^{N} F(\{P_n^*\}_{n=1}^{N})| > \varepsilon$, **do**

  a): $\{P_n^{(0)}\}_{n=1}^{N} = \{P_n^*\}_{n=1}^{N}$, update $\bar{x}_{n,1}$, $\bar{x}_{n,2}$, $\bar{t}$, $a_{n,1}$, $b_{n,1}$, $c_{n,1}$, $a_{n,2}$, $b_{n,2}$, $c_{n,2}$;

  b): solve convex problem $G(P_n)$, $\{P_n^*\}_{n=1}^{N} = \arg\max_{P_n} G(P_n)$;

  c): $l = l+1$;

**5**: **end while**.

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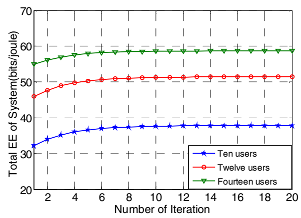


Fig. 1. The convergence of Algorithm 1 with $P_{\text{tot}}$=5 W.

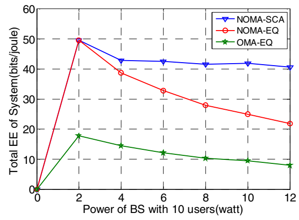


Fig. 2. Total EE of the system versus BS power with 10 users.

## V. Conclusion

In this paper, energy-efficient transmission design for downlink NOMA network is studied. We decompose inner-cluster power assignment and inter-cluster power allocation from each other. The optimal closed-form solution of the multi-users power allocation coefficients in each cluster is first determined. Then, we propose a low-complexity sub-optimal algorithm to further improve total EE. Simulation results show that NOMA performs better than OMA in terms of total EE and the proposed power allocation algorithm obviously achieves better performance than the equal power scheme.

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