Energy-Efficient Resource Allocation in Downlink GFDM-NOMA Networks

Yonghai Lin
Key Laboratory of Ministry of Education in Broadband Wireless Communication and Sensor Network Technology
Nanjing University of Posts and Telecommunications
Nanjing, China
Email: 2014010209@njupt.edu.cn

Zhen Yang
Key Laboratory of Ministry of Education in Broadband Wireless Communication and Sensor Network Technology
Nanjing University of Posts and Telecommunications
Nanjing, China
Email: yangz@njupt.edu.cn

Haiyan Guo
Key Laboratory of Ministry of Education in Broadband Wireless Communication and Sensor Network Technology
Nanjing University of Posts and Telecommunications
Nanjing, China
Email: guohy@njupt.edu.cn

***Abstract*—In this paper, the authors investigate the downlink radio resource allocation for wireless communications which consist of generalized frequency division multiplexing (GFDM) and non-orthogonal multiple access (NOMA). In our scheme, the whole frequency resource is divided into a lot of sub-carriers which are not always orthogonal and each subcarrier is allocated to multiple users according to NOMA principle. Energy efficiency (EE) is formulated under basic data rate requirements and the maximum transmitting power constraint of base station (BS). Due to the non-convex nature of the problem, we decompose it into two sub-problems: subcarrier allocation and power allocation. Subcarrier allocation is implemented in a greedy manner based on the predefined NOMA pairing principle and power allocation is transformed into a sequence of convex sub-problems by successive convex approximations. Numerical results demonstrate the correctness of our analysis and effectiveness of our algorithm. Additionally, GFDM can be easily integrated with cognitive radio to further enhance the performance of wireless communications.**

***Index Terms*—Energy-efficiency, GFDM-NOMA, resource allocation**

I. Introduction

With the booming traffic growth of wireless communications, non-orthogonal multiple access (NOMA) is envisioned as a powerful countermeasure to increase spectral efficiency (SE)[1, 2, 3]. By multiplexing two or more users on power domain at the transmitter and applying successive interference cancellation (SIC) technique at the receiver, co-channel interference is mitigated and signal is detected and decoded successfully. Due to the co-channel interference, NOMA network is interference-limited and it is impossible to ask all users to multiplex on the same frequency resource when there are many users. To tackle with it, hybrid multiple access (HMA) is proposed which consists of two or more multiple access [4, 5]. A promising one is NOMA combined with orthogonal frequency division multiplexing (OFDM) which can take advantage of OFDM and NOMA simultaneously [5]. It has been proved that OFDM-NOMA is superior to conventional orthogonal multiple access (OMA) in [6, 7, 8]. However, OFDM has some major drawbacks which hinder its application in 5G, such as strict synchronization and the cyclic prefix (CP) in OFDM symbol which leads to a low bandwidth efficiency. To deal with it, new techniques are proposed to replace OFDM. A candidate one is generalized frequency division multiplexing (GFDM) [9,10].

GFDM is first introduced in [11] and the idea of GFDM is filtering each sub-carrier with a pulse shaping filter on transmitting side to reduce out of band (OOB) emission. Recently, with development of advanced techniques, the OOB emission has been reduced significantly [12, 13, 14, 15,16]. In [14], a low OOB emission configuration for 5G air interface is proposed over different channels and a good performance of bit-error-rate is obtained. In [17], through time offset (TO) and carrier frequency offset (CFO) of multiple users, multiuser interference (MUI) cancellation technique for GFDM is proposed by weighted parallel interference cancellation (WPIC) and adaptive interference cancellation filter (AICF) for uplink transmission over Rayleigh fading channel. In [18], the spectral evaluation of GFDM systems over non-linear channels with memory is investigated. All these studies show that OOB emission can be effectively reduced for GFDM networks. On the other hand, GFDM can overcome the drawbacks of OFDM. E.g. a CP is used per dozens of transmitted symbols in GFDM, instead of appending a CP per symbol performed in OFDM [19]. As a result, SE of GFDM can be dramatically higher than that of OFDM [16]. In addition, GFDM requires loose time and frequency synchronization and it is easily integrated with cognitive radio which can further enhance SE, particularly for fragmented spectrum which cannot be utilized by OFDM. Due to the flexible nature and higher transmission efficiency, GFDM is proposed as an alternative of OFDM.

Besides SE on wireless communications, energy consumption has drawn more and more attentions in academic and industrial fields as well. In [20], it is estimated that percentage of the green-house gas emissions produced globally by information and communication technology (ICT) will account for

This work was supported by the National Natural Science Foundation of China (No. 61671252).

4% in 2020. To reduce energy consumption, energy efficiency (EE), which is the amounts of bits that can be delivered by per joule energy consumed in the system [21], has become a key technique and energy efficient design has become an inevitable trend in mobile communications. Currently, EE has been widely studied for NOMA system [20, 21, 22, 23]. In [20], The EE of NOMA system with imperfect CSI is optimized by resource allocation. In [21], EE transmission design for NOMA system is described in details. NOMA is extended to cognitive radio system and EE is optimized by fractional programming algorithm in [22]. EE is optimized for MIMO-NOMA system with second order statistic information in [23]. In [26], EE is optimized for hybrid mm-Wave communications by controlling beam-width. In [27], new technologies are proposed to improve the EE of wireless communications to enable sustainable green 5G networks. All these studies show the importance of the EE. However, EE of GFDM-NOMA has not drawn enough attentions. Motivated by these observations, in this paper, we study GFDM-NOMA networks from the perspective of EE. In our scheme, users are uniformly distributed in the cell and two users are selected to make up a NOMA pair. The total frequency resource is divided into different sub-carriers according to frequency division multiplexing. Each subcarrier is allocated to a NOMA pair. The EE objective is formulated under basic data rate requirement of each user and the maximum transmitting power constraint of base station (BS). It is a combinational problem and the exhaustive search is the unique way to obtain the optimal solution. To solve it within polynomial time, a low complexity algorithm is proposed to obtain a sub-optimal solution. The main contributions of our work are summarized as follows:

First, energy-efficient resource allocation is studied for GFDM-NOMA systems which can increase SE significantly and integrate with cognitive radio easily. Especially, GFDM-NOMA can increase the utilization of fragmented frequency resource. Second, EE is formulated and optimized for GFDM-NOMA systems. Due to the non-convex nature, we decompose it into subcarrier allocation and power allocation to obtain a sub-optimal solution with a low complexity. Simulation results demonstrate the correctness of our analysis and the effectiveness of our algorithm.

The remainder of the paper is organized as follows. Section II describes the system model and formulates EE objective. In section III, our low complexity algorithm is presented to obtain a sub-optimal solution. Section IV gives the numerical results and analysis. Conclusions are drawn in section V.

II. System Model

Consider a GFDM-NOMA system as shown in Fig.1. BS locates in the center of the cell and M users are uniformly distributed in the cell. To analyze it simply, we assume that all users and the BS are equipped with a single antenna. The multiple antennas can be easily extended to meet the practical demand. The total bandwidth of the system equals to B Hz and it is equally partitioned into N number of sub-carriers which are not always orthogonal. We denote n as the index of the n-th subcarrier where $n \in \{1, 2, ..., N\}$is the subcarrier set. We denote m as the index of the m-th user where $m \in \{1, 2, ..., M\}$ is the user set. Since NOMA is employed, each subcarrier is assigned to multiple users according to NOMA principle. In this paper, we assumed that a NOMA pair is made up of two users, therefore $M = 2N$.

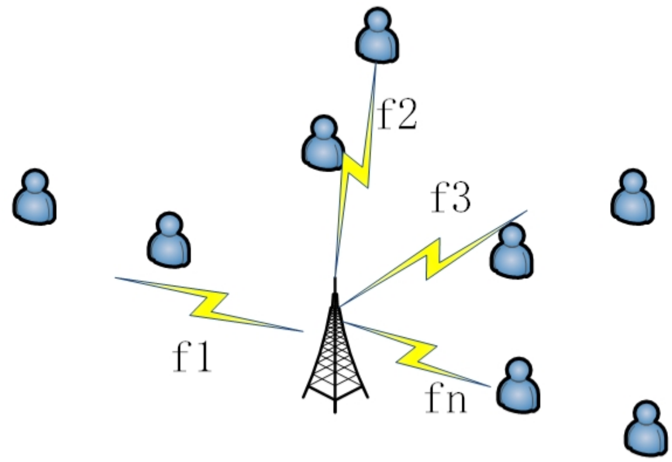

Fig. 1. Illustration of GFDM-NOMA system.

For a subcarrier n,$\forall n \in N$, U_{n1} and U_{n2} are selected to multiplex on it and they make up a NOMA pair. Without loss of generality, we assume that U_{n1} is near to the BS named by the strong user and U_{n2} is far from the BS named by the weak user. The BS transmits the superposed signal x_n on subcarrier n to U_{n1} and U_{n2} simultaneously.

$$x_n = \sqrt{\alpha_n p_n} x_{n1} + \sqrt{(1-\alpha_n) p_n} x_{n2}$$

where p_n denotes the transmitting power of BS on subcarrier n. α_n denotes the power allocation factor of U_{n1}, as a strong user in NOMA pair, there exists $\alpha_n \in (0, 0.5)$. x_{n1} and x_{n2} denote the information symbol of U_{n1} and U_{n2}. They are independent random variables with zero mean and unit variance, therefore $E[|x_{ni}|^2] = 1$,$i \in \{1, 2\}$. Following [14], a flexible pulse shaping filter D_n is utilized on transmitting side to reduce the OOB emission.

At the receiver end, a prototype filter F_n is utilized to further reduce the OOB emission. Therefore, U_{n1} and U_{n2} receive useful signal on sub-carrier n and the interference from neighboring subcarriers. The received signal of U_{n1} and U_{n2} can be written as follows:

$$y_{n2} = F_n h'_{n2} D_n x_n + \phi_{n2} + n_2 \tag{1}$$

$$y_{n1} = F_n h'_{n1} D_n x_n + \phi_{n1} + n_1 \tag{2}$$

where $h'_{ni}, i \in \{1, 2\}$ denotes the channel fading coefficient of user i with BS on subcarrier n. $\phi_{ni}, i \in \{1, 2\}$ denotes the OOB emission from neighboring subcarriers. n_1 and n_2

denote addictive white Gaussian noise (AWGN). We assume that AWGN is equal in the networks and $E[n_1^2] = E[n_2^2] = \sigma^2$.

Set $h_{n2} = F_n h'_{n2} D_n$,$h_{n1} = F_n h'_{n1} D_n$,equation (1) and (2) are transformed into following formulations:

$$y_{n2} = h_{n2} x_n + \phi_{n2} + n_2 \tag{3}$$

$$y_{n1} = h_{n1} x_n + \phi_{n1} + n_1 \tag{4}$$

Different from OFDM-NOMA, U_{n2} in GFDM-NOMA is interfered by power from NOMA technique, OOB emission and self-interference due to the non-orthogonal nature of GFDM and NOMA. According to NOMA protocol, U_{n2} treats the interference as noise and detects the information directly from the superposed signal. The signal to interference plus noise radio (SINR) of U_{n2} can be written as follows [17]:

$$\gamma_{n2} = \frac{|h_{n2}|^2 p_{n2}}{|h_{n1}|^2 p_{n1} + I_n^2 + \sigma^2} = \frac{g_{n2} p_{n2}}{g_{n2} p_{n1} + I_n^2 + \sigma^2} \tag{5}$$

where $g_{n2} = |h_{n2}|^2$ denotes the equivalent channel gain of U_{n2} on subcarrier n. I_n^2 denotes the interference including OOB emission and self-interference.$p_{n2} = (1 - \alpha_n) p_n$ is the allocated power of U_{n2}, $p_{n1} = \alpha_n p_n$ is the allocated power of U_{n1}. The instantaneous capacity of U_{n2} can be written as follows according to Shannon principle [24]:

$$r_{n2} = \log(1 + \gamma_{n2}) \tag{6}$$

As a strong user, U_{n1} implements SIC technique to obtain the corresponding information. It first detects and demodulates the information of user 2, then subtracts it from the superposed signal and finally the information of user 1 is obtained. Assuming that SIC can be done successfully, the SINR of user 1 can be written as:

$$\gamma_{n1} = \frac{|h_{n1}|^2 p_{n1}}{I_n^1 + \sigma^2} = \frac{g_{n1} p_{n1}}{I_n^1 + \sigma^2} \tag{7}$$

where $g_{n1} = |h_{n1}|^2$denotes the equivalent channel gain of U_{n1} on subcarrier n. I_n^1 denotes the interference including OOB emission and self-interference. The instantaneous capacity of U_{n1} can be written as follows according to Shannon principle [24]:

$$r_{n1} = \log(1 + \gamma_{n1}) \tag{8}$$

Following [20] [22], the total power consumed on sub-carrier n consists of two components, one is the transmitting power to U_{n1} and U_{n2}, the other is the circuit power consumed by BS. According to the definition of EE, the EE of the system on sub-carrier n can be written as follows:

$$\eta_n = \frac{r_n}{\xi_n p_n + p_{n,c}} = \frac{r_{n1} + r_{n2}}{\xi_n p_n + p_{n,c}} \tag{9}$$

where ξ_n is the reciprocal of the power amplifier efficiency.P_{nc} is the circuit power of BS on subcarrier n. P_{nc} is varied with data rate and it is a constant for a fixed data rate. We aim to optimize EE of the whole GFDM-NOMA network, as there are N subcarriers and $2N$ users, the global EE of the system can be written as follows:

$$\eta_{GEE} = \frac{\sum\limits_{m=1}^{2N} \sum\limits_{n=1}^{N} x_{mn} r_{mn}}{\sum\limits_{n=1}^{N} (p_n + p_{n,c})} \tag{10}$$

where x_{mn} denotes the subcarrier allocation index, if subcarrier n is allocated to user m, $x_{mn} = 1$, otherwise $x_{mn} = 0$. To guarantee the basic quality of service (QoS) of each user, a minimum date rate is required. It can be written as follows:

$$r_{ni} \geq R_{ni,\min} \tag{11}$$

Besides QoS requirements, there is a maximum transmitting power on each subcarrier and it can be written as follows:

$$p_{n1} + p_{n2} \leq P_{n,\max}, \forall n \in N \tag{12}$$

For the BS, there is a maximum transmitting power and it can be written as follows:

$$\sum_{n=1}^{N} p_n \leq P_{\max} \tag{13}$$

From aforementioned analysis, the EE objective function of GFDN-NOMA system can be written as follows:

$$\eta_{GEE} = \frac{\sum\limits_{m=1}^{2N} \sum\limits_{n=1}^{N} x_{mn} r_{mn}}{\sum\limits_{n=1}^{N} (p_n + p_{n,c})} \tag{$P1$}$$

$$\begin{aligned} s.t. \quad & r_{ni} \geq R_{ni,\min} && (P1-1) \\ & p_{n1} + p_{n2} \leq P_{n,\max}, \forall n \in N && (P1-2) \\ & \sum_{n=1}^{N} p_n \leq P_{\max} && (P1-3) \\ & x_{mn} \in \{0, 1\} && (P1-4) \end{aligned}$$

From problem (P1), it can be observed that EE of GFDM-NOMA is similar with that of OFDM-NOMA. In facte, the resource allocation of GFDM-NOMA is more complex due to the non-orthogonality nature of GFDM. Meanwhile, the objective function of EE in problem (P1) consists of discrete variable x_{mn} and constant variable p_n, it is a combinational problem and it is not convex. (P1-1) is the basic QoS requirement which is not convex as well. (P1-2) and (P1-3) are power constrains which are linear constraints and (P1-4) is a discrete constraint. Therefore it is challenging to find the global optimal solution within a polynomial time. In the paper, a low complexity algorithm is proposed to obtain a sub-optimal solution.

III. Optimization of Global EE

In this section, we solve problem (P1) by our proposed low complexity algorithm to obtain a sub-optimal solution. We decompose the original problem into two sub-problems, subcarrier allocation and power allocation. Two sub-problems are solved independently.

A. Subcarrier Allocation

As each subcarrier is allocated to two users who are selected according to NOMA principle, it can be solved by enumerating all candidate user sets to find the optimal solution. With the increasing of users, it is impossible to realize in practice. To complete subcarrier allocation, we first pre-define user pairing principle according to NOMA protocol. According to the principle defined in [25], there are two common pairing principle as shown in Fig.2 and Fig.3. All users are ordered according to their channel state information (CSI), such as $|h_1|^2 \geq |h_1|^2 \geq ... \geq |h_N|^2 >> |h_{N+1}|^2 \geq |h_{N+2}|^2 \geq ... \geq |h_{2N}|^2$. Fig.2 demonstrates the first principle, User 1 and user $2N$ are selected to form a NOMA pair, user 2 and user $2N-1$ are selected to form next NOMA pair, and so on until all users are paired completely. Fig.3 demonstrates the second principle, user 1 and user $N+1$ are selected to form a NOMA pair, user 2 and user $N+2$ are selected to form next NOMA pair, and so on until all users are paired completely. In the paper, we adopt the first principle.

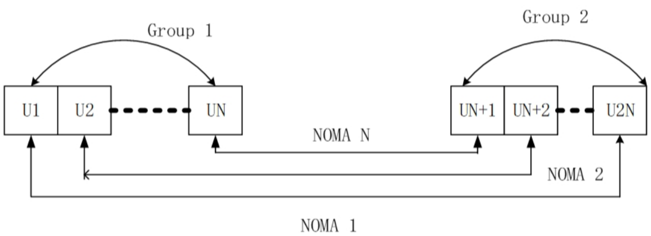

Fig. 2. Illusion of user pairing A.

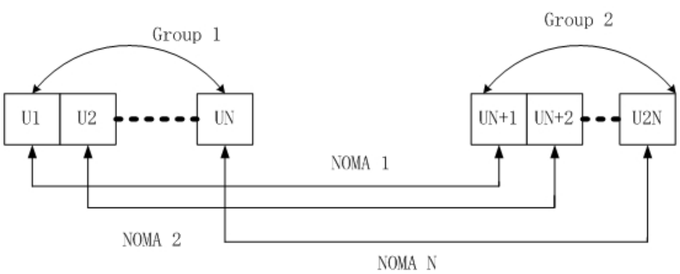

Fig. 3. Illusion of user pairing B

Based on the predefined NOMA pair principle, subcarrier allocation can be completed. As there are N subcarriers and N NOMA pairs, the optimal allocation is obtained only by the exhaustive search. The complexity is still too high to realize in practice. To obtain a sub-optimal allocation, a greedy algorithm is proposed and it is summarized as follows.

We denote U_{unAll} as the sets of allocated users and SC_{unAll} as the sets of allocated subcarriers. We denote U_{all} as the set of users who have been allocated successfully. We first find the user who has the best channel gain and allocate it to the corresponding sub-channel. On this sub-channel, the corresponding pairing user is selected from the pre-defined

Algorithm 1 greedy algorithm for subcarrier allocation

1. Establish the channel matrix $H_{M\times N}$,
2. Initialize sets of U_{unAll} and SC_{unAll}
3. Initialize the allocated user set $U_{all} \in \Phi$
4. For $n = 1 : N$
5. $(m, n) = \max H$, subcarrier n is allocated to user m;
   $\pi(m) = \min H(:, n)$, user $\pi(m)$is selected to pair with user m
   $U_{all} = (m, \pi(m))$,$SC_{unall} = SC_{unall} \backslash n$,
   $U_{unall} = U_{unall} \backslash (m, \pi(m))$
8. end for

until all users are paired completely.

user pairing principle. A NOMA pair is formulated. Users and sub-carrier are deleted until all users are completely paired.

Complexity analysis, consider there are KN users and N subcarriers in the system, the complexity of the exhaustive search is O(2^{KN}).For greedy algorithm, the complexity is O(KN^2). It can be easily observed that the complexity is reduced significantly. In the paper, $K = 2$, the complexity of the algorithm is decreased from O(2^{2N}) to O($2N^2$).

B. Power allocation

Since subcarrier allocation has been completed, power allocation can be transformed into problem (P2). To solve it, we define $\mathbf{P} = [p_1, p_2, ..., p_N]$ which denotes the transmitting power of N sub-carriers. To guarantee basic QoS of each user, there exists a minimum power $\mathbf{P}_{n,\min} = [p_{1,\min}, p_{2,\min}, ..., p_{N,\min}]$ for each sub-carrier. We assume $\mathbf{P} \succ \mathbf{P_{min}}$ always holds true in the following sections.

$$\eta_{GEE} = \frac{\sum_{i=1}^{N} r_n}{\sum_{i=1}^{N} (p_n + p_{n,c})} \qquad (P2)$$

$$\begin{aligned} s.t. \quad & r_{ni} \geq R_{ni,\min} && (P2-1) \\ & p_{n1} + p_{n2} \leq P_{n,\max} && (P2-2) \\ & \sum_{n=1}^{N} p_n \leq P_{\max} && (P2-3) \end{aligned}$$

To problem (P2), for a given feasible region $\mathbf{P}$, due to the fractional form of EE and log-function is concave. It is a non-convex problem. We adopted successive convex approximation to solve it. According to the equality: $\log(1+z) \geq \alpha \log z + \beta$ where α and β are defined as:

$$\alpha = \frac{z_0}{1+z_0}, \beta = \log(1+z_0) - \frac{z_0}{1+z_0} \log z_0 \qquad (14)$$

when $z = z_0$, the bound is tight. The problem (P2) can be written as

$$\eta_{GEE}(\mathbf{P}) \geq g(\mathbf{P}) = \frac{\sum_{n=1}^{N} \alpha_n \log \gamma_n + \beta_n}{\sum_{n=1}^{N} (p_n + p_{n,c})} \tag{15}$$

s.t. (P2-1),(P2-2),P(2-3)

This can be solved by the standard fractional procedure. Although problem (P2) can be solved by standard fractional procedure, equation (15) is still hard to solve. To reduce the complexity of the equation, we adopt Taylor approximation to solve it.

For a sub-carrier n, we set

$$\begin{aligned} F(p_n) &= \alpha_{n2} \log \gamma_{n2} + \beta_{n2} + \alpha_{n1} \log \gamma_{n1} + \beta_{n1} \\ &= \alpha_{n2} \log p_{n2} g_{n2} - \alpha_{n2} \log(p_{n1} g_{n2} + I_n^2 + \sigma^2) \\ &+ \beta_{n2} + \alpha_{n1} \log(p_{n1} g_{n1}) + \beta_{n1} - \log(I_n^1 + \sigma^2) \end{aligned} \tag{16}$$

We set

$$f(p) = \alpha_{n2} \log p_{n2} g_{n2} + \beta_{n2} + \alpha_{n1} \log(p_{n1} g_{n1}) + \beta_{n1} \tag{17}$$

$$h(p) = \alpha_{n2} \log(p_{n1} g_{n2} + I_n^2 + \sigma^2) + \log(I_n^1 + \sigma^2) \tag{18}$$

Equation (15) can be transformed into following equations:

$$\begin{aligned} \max F(p, q) &= \sum_{n=1}^{N} F(p_n) - q \times g(p_n) \\ &= \sum_{n=1}^{N} [f(p_n) - h(p_n) - q \times g(p_n)] \end{aligned} \tag{19}$$

In equation (18), $g(p)$ is a linear function. $f(p)$ is log-function which is concave, therefore $-f(p)$ is convex. $-h(p)$is a concave function and it is approximated by Taylor's expression. It can be expressed by equation (19).

$$\log f(x) \approx f(x_0) + f'(x_0)(x - x_0) \tag{20}$$

Equation (16) is transformed into a convex function, and the constraints are linear function. It can be solved by s-tandard CVX toolbox.It can be solved in polynomial time. In practice, first-order Taylor expansion has a low precise solution. It is adopted in a limited scope. To solve it, a piece-wise linear equation is proposed. The initial point is set as $0, 0.2P, 0.4P, 0.6P, 0.8P$. The maximum solution is obtained from the five initial points. Here we omit the algorithm.

C. Integration GFDM-NOMA with Cognitive radio

As a promising technique of 5G, GFDM can be easily integrated with cognitive radio which can detect null frequency spectrum. As the null frequency spectrum is usually fragmented and the orthogonality cannot be guaranteed. It is hard to utilize by OFDM who required strict orthogonality. Meanwhile, GFDM can overcome this disadvantage and prominently increase the bandwidth efficiency. Considered the scarce frequency resource, integration of GFDM and cognitive radio can effectively increase the bandwidth efficiency.

IV. Simulation Results

In this section, simulation results are presented to confirm the correctness of our analysis and the effectiveness of our algorithm. As a benchmark, the EE performance of OFDM-NOMA is given as well. We assume that the bandwidth of GFDM-NOMA and OFDM-NOMA is equal and the fragmented spectrum is not considered. In our simulations, the radius of the cell is set to $500m$.The channel fading is Rayleigh fading, Log-Normal shadowing with standard deviation 8dB and the path-loss model $PL(d) = PL_0(d_0/d)^{3.8}$ where $d \geq d_0$ is the distance in meters and PL_0 is the free-space attenuation at the reference distance $d_0 = 20m$. The bandwidth is $200kHz$. The filter for GFDM is RC filter with $\alpha = 0.1$ at the transmitting side and prototype filter follows in [17] at the receiver. AWGN is set to $-174dBm/Hz$. The reciprocal of power amplifier ξ is set to 3.

Fig.4 gives the comparison of EE between GFDM-NOMA and OFDM-NOMA networks with different QoS requirements. The basic QoS of cell edge user is set $R_{min} = 2b/s/Hz, R_{min} = 1.5b/s/Hz$ and $R_{min} = 1b/s/Hz$ respectively. The corresponding circuit power is set to $750mW$,$600mW$ and $450mW$. As there exist ICI and OOB emission in GFDM-NOMA network and perfect orthogonality and synchronization is assumed in OFDM-NOMA network. The EE of the GFDM-NOMA is slightly lower than that of OFDM-NOMA. In practice, perfect synchronization and orthogonality is impossible to obtain, the difference will become less than that from the ideal scenario.

In our simulations, we do not consider the influence of fragmented frequency spectrum. In practice, the effective bandwidth efficiency of GFDM will become much higher than that of OFDM due to no requirement of orthogonality. On the other hand, from Fig.4 and Fig.5, it can be observed that EE cannot keep increasing with the increasing of transmitting power for both OFDM-NOMA and GFDM-NOMA. Once the maximum EE is obtained, it will decrease significantly with the increasing of the transmitting power, thus it is not an effective strategy to enhance EE by increasing the transmitting power uniquely. Ee can be enhanced prominently in heterogeneous network by deploying small antennas in macro-cell.

Fig.5 gives the comparison of EE between GFDM-NOMA and OFDM-NOMA based on the effective data rate. We set the total length of each OFDM symbol is 128 bits which consists of 16 bits CP and 112 bits data, the effective data rate is 87.5%. For GFDM-NOMA, two types of frames are

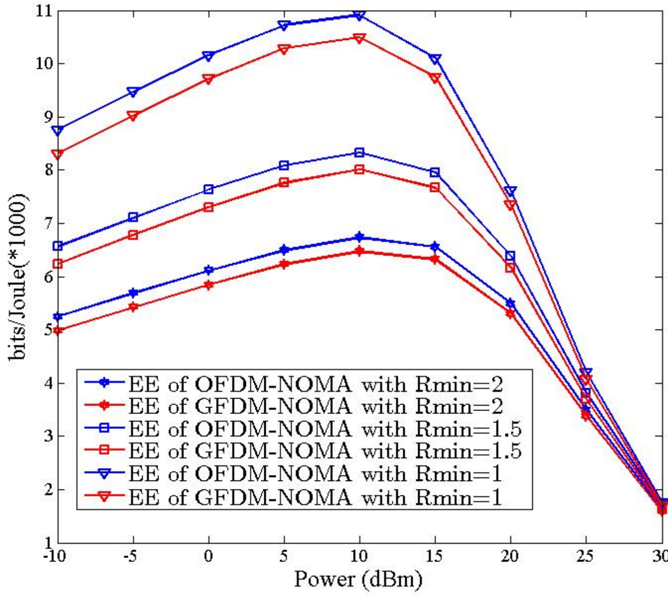

Fig. 4. EE comparison between OFDM-NOMA and GFDM-NOMA

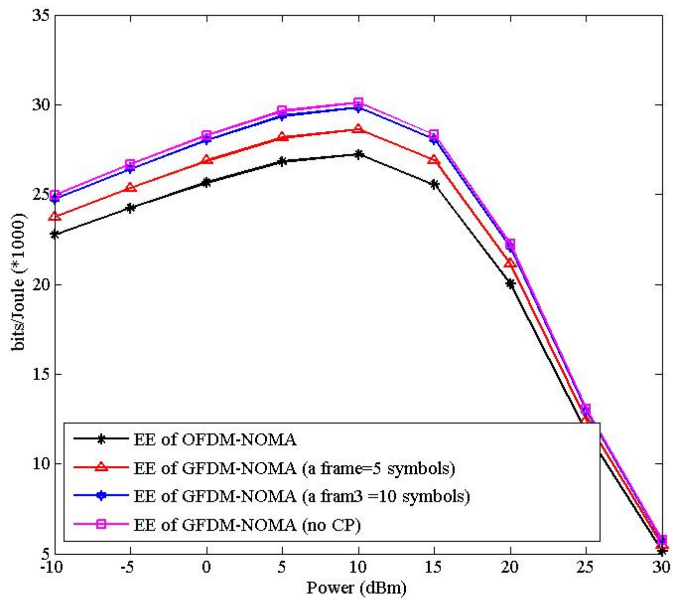

Fig. 5. Effective EE comparison between OFDM-NOMA and GFDM-NOMA

considered. The length of frame equals to 5 OFDM symbol and 10 OFDM symbol respectively. As a benchmark, a data stream without CP is considered as the upper bound which denotes that effective data rate is 100%. From Fig.5, the EE of GFDM-NOMA is superior to OFDM-NOMA. According to our aforementioned analysis, for OFDM-NOMA, each symbol has 16 bits useless data, this decreased the effective data rate significantly. Meanwhile for GFDM, CP is only inserted in each frame which consists of several symbols. In particular, when a frame of GFDM-NOMA consists of 10 symbols, effective data rate is almost 100%. The influence of CP can be almost neglected and bandwidth efficiency is increased.

Fig.6 gives the EE of cell edge user with different QoS requirements. From Fig.6, the EE of cell edge users is low compared to the total EE of the system. This is mainly caused by that fact that cell edge user is far from the BS, the channel fading coefficient is larger than that of near user. To obtain the equal data rate with cell center user, it needs more transmitting power. The EE of the whole network is influenced as well. It is impetus to increase the EE of the cell edge users. To solve it, maybe dense cell deployment with a low transmitting power is an effective way.

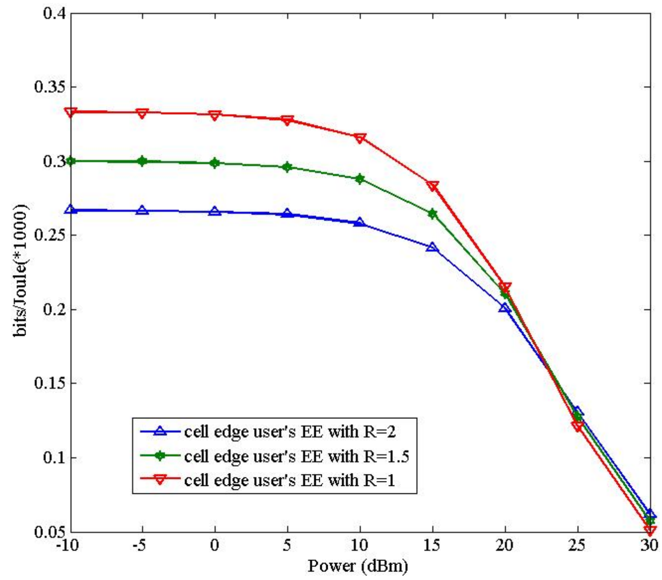

Fig. 6. EE of cell edge users with different QoS

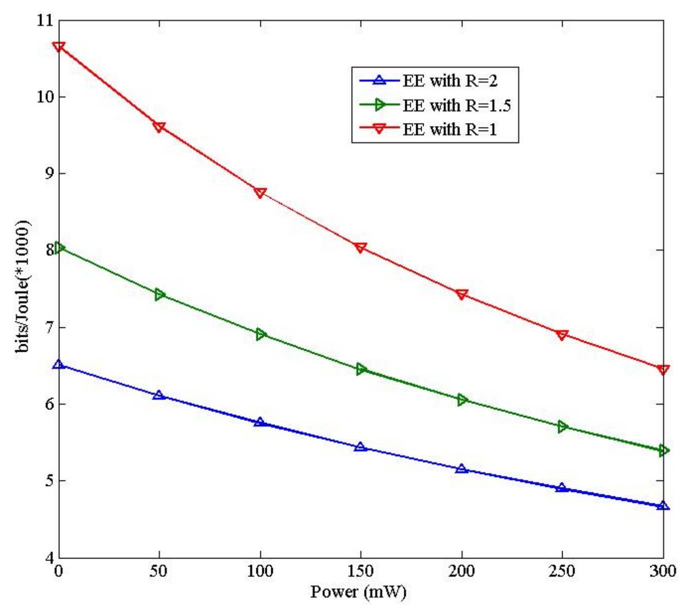

Fig. 7. EE versus circuit power

Fig.7 gives the EE of the whole network with different QoS requirements versus circuit power. We can see, with the increasing of the circuit power, EE decreases significantly. Thus, it is an effective strategy to develop energy efficiency device for future wireless communications.

V. CONCLUSION

In the paper, we study EE of GFDM-NOMA systems by resource allocation. EE is formulated with constraints of maximum transmitting power and basic QoS requirements. As a non-convex problem, we divide the problem into two sub-problems, sub-carrier allocation and power allocation to obtain a sub-optimal EE. Subcarrier allocation is implemented in a greed manner and power allocation is solved by successive convex approximation. Numerical results confirm the advantages of GFDM-NOMA compared to OFDM-NOMA. To further increase EE of wireless communications, heterogeneous network will be investigated in our future work.

ACKNOWLEDGMENT

The authors would like to thank Yan Liu for her suggestions and comments which had helped to improve the quality of the paper.

REFERENCES

[1] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li and K. Higuchi, "Non-orthogonal multiple access (NOMA)for cellular future radio access," 2013 IEEE 77thVehicular Technology Conference (VTC Spring), 2013:1-5.

[2] Y. S Benjebbouaito, A.r, Y. Kishiyama, T. Nakamura, "System-level performance evaluation of downlink non-orthogonal multiple access (NOMA)," 2013 IEEE 24th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), 2014: 706-710.

[3] Q. Sun, S. Han, C.-L. I and Z. Pan, "On the Ergodic capacity of MIMO NOMA systems," IEEE Wireless Comm. Lett., vol. 4, no. 4, PP: 405-408, Aug. 2015.

[4] Zhiguo Ding ; Yuanwei Liu ; Jinho Choi ; Qi Sun ; Maged Elkashlan ; Chih-Lin I ; H. Vincent Poor, "Application of Non-orthogonal Multiple Access in LTE and 5G Networks,"IEEE Communications Magazine, Year: 2017 , Volume: 55 , Issue: 2, Pages: 185 - 191

[5] Z. Ding, P. Fan, and H. V. Poor, "Impact of User pairing on 5G Non-orthogonal Multiple access," IEEE Trans Commun., (submitted) Available on line at arXiv:1412.2799

[6] Parida, P., Das, S, "Power allocation in OFDM based NOMA systems: a DC programming approach," Proc. Int. Conf. IEEE Globecom Workshops (GCWkshps), December 2014, pp. 1026-1031

[7] Wenbo Cai ; Chen Chen ; Lin Bai ; Ye Jin ; Jinho Choi, "Subcarrier and power allocation scheme for downlink OFDM-NOMA systems."IET Signal Processing, Year: 2017 , Volume: 11 , Issue: 1, Pages: 51 - 58

[8] Wenjun Xu ; Xue Li ; Chia-Han Lee ; Miao Pan ; Zhiyong Feng, "Joint Sensing Duration Adaptation, User Matching, and Power Allocation for Cognitive OFDM-NOMA Systems," IEEE Transactions on Wireless Communications. Year: 2018 , Volume: 17 , Issue: 2, Pages: 1269 - 1282

[9] G.Fettweis and S. Alamouti, "5G: Personal mobile internet beyond what cellular did to telephony," IEEE Communications Magazine, vol.52, no. 2, pp. 140-145, February 2014.

[10] N. Michailow et al., "Generalized frequency division multiplexing for 5th generation cellular networks," IEEE Trans. Commun., vol. 62, no. 9, pp. 3045-3061, Sep. 2014.

[11] G.Fettweis, M. Krondorf, and S. Bittner, "GFDM-Generalized frequency division multiplexing," in Proc. IEEE 69th Veh. Technol. Conf.(VTC-Spring), Barcelona, Spain, Apr. 2009, pp. 1-4.

[12] N.Michailow et al., "Generalized frequency division multiplexing for 5th generation cellular networks," IEEE Trans. Commun., vol. 62, no. 9, pp. 3045-3061, Sep. 2014.

[13] Yuan Niu ; Jianping Zheng, "Message Passing Algorithm for GFDM-IM Detection," 2018 IEEE 23rd International Conference on Digital Signal Processing (DSP), Year: 2018, pp: 1-5.

[14] Ivo Bizon Franco de Almeida ; Luciano Leonel Mendes, "Linear GFDM: A Low Out-of-band Emission Configuration for 5G Air Interface," 2018 IEEE 5G World Forum (5GWF)Year: 2018, pp: 311-316.

[15] N. Michailow et al., "Generalized frequency division multiplexing for 5th generation cellular networks," IEEE Trans. Commun., vol. 62, no. 9, pp. 3045-3061, Sep. 2014.

[16] B. Farhang-Boroujeny and H. Moradi, "OFDM inspired waveforms for 5G," IEEE Comm. Surveys Tuts., vol. 18, no. 4, pp. 2474-2492, 4th Quart., 2016.

[17] Byungju Lim ; Young-Chai Ko, "Multiuser Interference Cancellation for GFDM with Timing and Frequency Offsets," 2018 IEEE Wireless Communications and Networking Conference (WCNC), Year: 2018, Pages: 1-6

[18] Alexander Hilario-Tacuri ; Jose Mauro P. Fortes ; Raimundo Sampaio-Neto, "Analytical spectral evaluation of GFDM systemsover non-linear channels with memory," 2018 IEEE 10th Latin-American Conference on Communications (LATINCOM)Year: 2018, Pages: 1-5.

[19] N. Michailow et al., "Generalized frequency division multiplexing for 5th generation cellular networks," IEEE Trans. Comm., vol. 62, no. 9,pp. 3045-3061, Sep. 2014.

[20] Yi Zhang, Hui-Ming Wang, Tong-Xing Zheng, Qian Yang, "Energy efficient transmission for downlink non-orthogonal multiple access network," IEEE Transactions on Vehicular Technology, Year: 2017, vol:66, Issue: 3. PP: 2852-2857.

[21] Yi Zhang , Qian Yang, Tong-Xing Zheng,Hui-Ming Wang, Ying Ju,Yue Meng, "Energy Efficiency Optimization in Cognitive Radio Inspired Non-Orthogonal Multiple Access," 2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), Year: 2016. Pages: 1 - 6

[22] Q. Sun, S. Han, C.-L. I and Z. Pan, "Energy efficiency optimization for fading MIMO non-orthogonal multiple accesssystems," 2015 IEEE International Conference on Communications (ICC),June 2015, pp. 2668-2673.

[23] Fang Fang, Haijun Zhang, Julian Cheng, Victor C.M. Leung, "Energy-efficient Resource Scheduling for NOMA Systems With Imperfect Channel State Information," 2017 IEEE International Conference on Communications (ICC). Year: 2017, PP: 1-5.

[24] D. Tse and P. Viswanath, *Fundamentals of Wireless Communication*. Cambridge, U.K. : Cambridge Univ. Press 2005.

[25] MD Shipon Ali ; Hina Tabassum ; Ekram Hossain, "Dynamic User Clustering and Power Allocation forUplink and Downlink Non-Orthogonal Multiple Access (NOMA) Systems," IEEE Access, Year: 2016 , Volume: 4, Pages: 6325-6343.

[26] Z. Wei, D. W. K. Ng and J. Yuan, "NOMA for Hybrid mmWave Communication Systems With Beamwidth Control," IEEE Journal of Selected Topics in Signal Processing, vol. 13, no. 3, pp. 567-582, June 2019.

[27] Q. Wu, Y. Li, W. Chen, D. W. K. Ng and R. Schober, "An Overview of Sustainable Green 5G Networks," IEEE Wireless Communications, vol. 24, no.4, pp. 72-80, Aug. 2017.