Power Control Optimization of Multi-user Uplink based on NOMA

Hongwei Li[1], Xiaoli He[1, *], Yu Song[2], Zhen Zeng[1], Haimin Yi[1]

[1] School of Computer Science, Sichuan University of Science and Engineering, Zigong 643000, China

[2] Department of Network Information Management Center, Sichuan University of Science and Engineering, Zigong 643000, China

Abstract

Non-orthogonal Multiple Access (NOMA) has recently been recognized as a key enabling technology for 5G cellular systems. In NOMA, multiple users are multiplexed into the transmission power domain by exploiting the channel gain difference, and then non-quadratically scheduled transmission over the same spectral resource. Continuous interference cancellation (SIC) is then applied at the receiver to decode the message signal. In this paper, the base station generates a large-scale beam set covering the whole cell through beam forming, and carries out non-orthogonal unicast and multicast communication with the user, that is, sends unicast and multicast signals to the user at the same time on the same time-frequency resources. Aiming at maximization of system energy efficiency (EE), the statistical channel state information of each user is obtained by the base station, and the users are divided into two groups: central users and edge users. At the same time, constraints such as the group distance limit between central users and edge users, the maximum transmitting power limit of users, and the minimum transmission rate limit of users are satisfied. And implement non - orthogonal unicast multicast transmission power allocation with optimal energy efficiency. Based on the traditional near and far matching algorithm and the UCGD algorithm, the group distance limit between users is proposed. By using the certainty identity principle, MM method, alternate optimization method and Dinkelbach transform, the optimal sending signal matrix is obtained by solving a series of convex optimization subproblems through multi-layer iteration. When the channel state between the base station and each user changes, the base station can dynamically allocate the transmission power of each group user to achieve the goal of optimal energy efficiency. In this paper, the proposed algorithm based on the improved model has low complexity, can effectively improve the transmission rate of edge users, and can significantly improve the energy efficiency of large-scale MIMO non-orthogonal unicast multicast transmission.

Keywords

Cognitive Radio Network; NOMA; Spectrum Resource Allocation; EE; Dinkelbach Algorithm.

1. Introduction

As one of the rarest and most precious natural resources in the world, the radio spectrum is divided by the radio management departments of each country. With the development of communication technology, more and more signal forms and a variety of wireless communication systems and wireless standard protocols emerge along with the diversity of communication business, and the communication industry has begun to show a prosperous prospect. As a key technology of 5G, NOMA has attracted extensive attention from researchers in various academic fields at home and abroad, and there are a lot of research achievements in NOMA.

Foreign authors mainly focus on the design of SIC receiver based on NOMA, resource scheduling scheme in NOMA scenario and NOMA capacity maximization of downlink and other key technologies of CR system. Reference [1] describes the concept of NOMA resource scheduling, and it also points out that the SIC receiver is taken as the basic receiver at the receiving end to realize the correct reception of the expected signal. Literature [2] proposes a new resource scheduling scheme SC-NOMA based on the ascending NOMA scenario, and simulation results show that this scheme can achieve better throughput performance than M orthogonal multiple access pilots (OMA). Literature [3] summarizes the performance advantages and potential gains of NOMA compared with OFDMA, and points out that the essence of NOMA is to exchange the improvement of system capacity and spectral efficiency at the cost of the complexity of the receiver. Literature [4] proposes an optimal energy efficiency power allocation scheme for uplink multi-carrier non-orthogonal multiple access (MC-NOMA) system based on user equity. Literature [5] proposes a variety of user pairing schemes based on channel gain, including traditional near-far pairing scheme, uniform channel gain differential pairing scheme (UCGD) pairing scheme and mixed pairing scheme. In addition, a virtual user pairing scheme was proposed in literature [6] to maximize the capacity of downlink NOMA.

Detailed studies on SIC receiver design, NOMA and OMA comparison, uplink multi-carrier power distribution and other aspects are given in the above literature, but few studies are conducted on NOMA based multi-user uplink power control optimization using joint optimization technology to improve the maximum receiving rate of the base station. Nor does the above problem extend to the uplink multi-channel, multi-user case. These less studied problems are exactly the key technologies to study the dynamic spectrum of CRN.

Domestic authors focus on the key technologies of CR systems based on NOMA dynamic spectrum access, resource management and allocation. In literature [7], the perception time allocation of multi-channel is modeled as a convex optimization problem, and the cross-layer resource allocation problem in CRN is studied, including heterogeneous network coexistence problem and dynamic spectrum access problem. Literature [8] proposes a method to estimate the interference temperature of the whole airspace by using the sample values of several spatially distributed sensors and combining with Kriging estimation method. Literature [9] proposes a spectrum sensing strategy based on wavelet transform and interference temperature estimation. Literature [10] proposes an improved interference temperature model to improve the spectrum utilization of cognitive users. The spatial parameters are introduced into the traditional interference temperature model and an improved interference temperature model is established in the frequency domain. Literature [11] has made an in-depth study on the spectrum cavity detection process based on interference temperature detection. Based on the study of the restriction conditions of user interference, the detection method of the spectrum hole at the SU receiving and sending terminal is given. The steps of SU and PU information interaction are proposed. Literature [12] proposed a two-factor binary search optimization power allocation algorithm based on the traditional waterflood power allocation algorithm, aiming at the problems such as the SU base station's inability to reasonably allocate its transmitting power and effectively improve the data transmission rate. The algorithm fully considers the limit of interference temperature on SU channel.

In the above literature, the interference temperature has been studied in detail in the aspects of spectrum access, spectrum sensing, spectrum hole detection, power distribution, etc. The many-to-many matching model, water filling and geometric programming are used to improve the system performance, but less research has been done on the NOMA based multi-user uplink power control optimization using joint optimization technology to improve the maximum receiving rate of the base station. These less studied problems are exactly the key technologies for the study of dynamic spectrum connection of CRN.

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2. Related Work of this Paper

In the related work of this study, a multi-user uplink grouping scheme and energy efficiency maximization optimization method based on NOMA are proposed. After studying the characteristics of the user and the nature of the objective function, the user group distance constraint is proposed to optimize the group, and the Dinkelbach algorithm is used to solve the power distribution problem optimally. The dynamic distribution of the transmission power of each group user is used to achieve the goal of the optimal energy efficiency, so as to maximize the throughput of multi-user communication.

3. System and Network Model

3.1 System Model

The system consists of a cell covered by a single base station and multiple users. The base station has a P antenna array as a signal receiving antenna and is located in the center of the cell. N single antenna transmitter users are randomly generated in the coverage range of the base station. Each user sends a signal to the base station with its own independent transmitting power, and the transmitting power of each user is limited by its own maximum transmitting power. As long as there is sufficient difference between the channel gain of different users, they can use the maximum transmitting power for transmission, so as to obtain better system performance. The channel between each user and the base station is different, and the user with good channel quality may have stronger transmission power. The SIC receiver is configured at the base station end, and the in-cluster interference is the sum of the channel gain of other users. The interference of users mainly comes from the users with good channel quality, that is, the users with poor channel quality are more susceptible to strong in-cluster interference. Firstly, the user with good channel quality is decoded, and the signal with the strongest interference is subtracted from the stack signal. Secondly, the user with inferior channel quality is decoded, and so on until all the signals are decoded. If the user with poor channel quality is decoded first, it needs to allocate high transmitting power to ensure its receiving power, which will cause a waste of resources.

The uplink model is shown as follows:

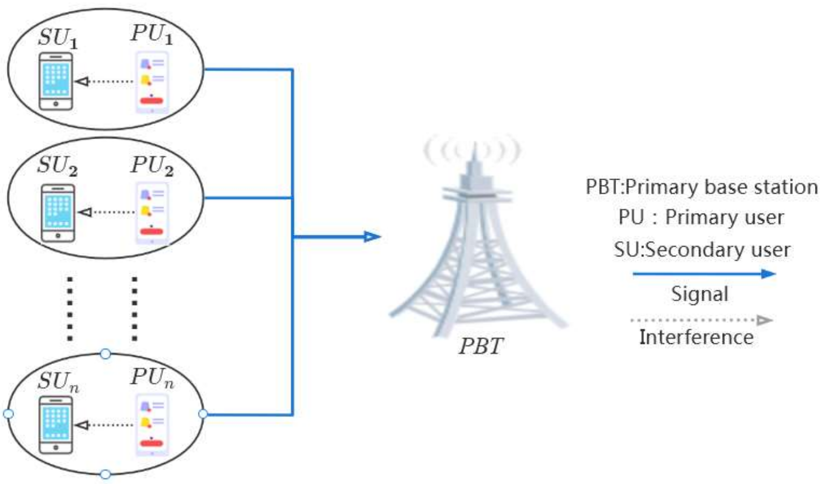

Fig. 1 Uplink model diagram

In order to balance the tradeoff between computational complexity and improved performance of the NOMA system, all users are divided into central users (primary users) and marginal users (secondary users) based on channel state information. The central users and edge users were divided into M clusters according to the user pairing distance limit, and each cluster had at least 1 user and at most 2

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users. If the number of paired user clusters is M and the available bandwidth is evenly allocated, the bandwidth occupied by each user cluster can be expressed as $B = B_t / N$. The K-TH user in the N-TH cluster is represented by Unk, where n∈{1, ⋯, M} and k∈{1, ⋯, K}. The uplink channel state between the Unk and the base station is represented in gnk and modeled as:

$$g_{nk} = \tilde{g}_{nk} \zeta_{nk}^{1/2} \quad (1)$$

And ˜gnk ~ CNM×1 (0M×1, IM) captures the independent and isodistributed frequency flat small-scale Rayleigh fading, while ζnk captures the large-scale fading of Unk. Therefore, the M ×NK dimensional full uplink channel matrix between NK user and BS is represented by G, which can be written as follows by connecting the uplink channel vector (gnk) :

$$G = [g_{11}, \cdots, g_{1K}, \cdots, g_{n1}, \cdots, g_{nK}, \cdots, g_{M1}, \cdots, g_{MK}] \quad (2)$$

The channel matrix G1 and G2 of central user and edge user are shown as follows:

$$G_{center} = [g_{1,1}, g_{1,2}, \cdots, g_{1,M}] \quad (3)$$

$$G_{edge} = [g_{2,1}, g_{2,2}, \cdots, g_{2,M}] \quad (4)$$

$$g_{1,1} \geq g_{1,2} \geq \cdots \geq g_{1,M} \geq g_{2,1} \geq g_{2,2} \geq \cdots \geq g_{2,M} \quad (5)$$

When the channel of central user and edge user is shown as above, the received signal y at the base station can be represented as follows:

$$y = \left(G_{center} x_1 + G_{edge} x_2\right) + n \quad (6)$$

As shown above, the base station receives the superimposed signal of all users in the same group. The central user has a strong signal-to-noise ratio in the base station, so the central user is decoded first. Finally, the edge user is decoded by SIC using the detection signal of the central user.

Xk represents the transmitted signal of user k; n is a noise vector with an additive mean of 0 and a variance of σ2. We apply a transmission power limit to each user k.

$$E\left[\left|x_k\right|^2\right] \leq P \quad (7)$$

Considering that RL,1 and RM,2 respectively represent the rate of the L and M th users of the central user and the edge user in the case of perfect SIC, the user data rate that can be realized can be calculated by the following formula:

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$$R_{1,L} = B\log_2\left(1+\frac{\rho\beta_{1,L}\left|h_{1,L}\right|^2}{\rho\beta_{2,M}\left|h_{2,M}\right|^2+1}\right) \tag{8}$$

$$R_{2,M} = B\log_2\left(1+\rho\beta_{2,M}\left|h_{2,M}\right|^2\right) \tag{9}$$

Where, ρ represents the sent signal to noise ratio, $\rho = P_t / \omega$ .Therefore, the total data rate that can be achieved can be obtained from the above equation:

$$R_{sum} = \sum_{L=1}^{N} R_{1,L} + \sum_{M=1}^{N} R_{2,M} \tag{10}$$

3.2 User Pairing Scheme Design:

The edge users need to rely on the joint grouping of the central users to improve the overall communication rate of the system, but the edge users' signals will affect the central users' signals, which is called interset interference. Therefore, user pairing and grouping between central users and marginal users has become an extremely important issue. In this section, two user pairing schemes are studied for the purpose of maximizing the total system capacity of the ascending NOMA, and compared with the traditional near and far pairing scheme and UCGD pairing scheme, simulation results show that the optimized scheme is superior to the traditional scheme.

1) Traditional near and far matching scheme. In order to maintain the maximum channel gain difference among paired users, the user with the largest channel gain is paired with the user with the smallest channel gain. Intermediate users with similar channel gain are paired with each other. However, because the channel gain difference between cell intermediate users is very small, strong interset interference will be generated after pairing. Pair the user with the highest channel gain among the central users with the user with the lowest channel gain among the edge users. The user with the second highest channel gain in the central user is then paired with the user with the second lowest channel gain in the edge user set, and so on.

$$\begin{bmatrix} \text{User cluster 1} \\ \text{User cluster 2} \\ \cdots \\ \text{User cluster M} \end{bmatrix} = \begin{bmatrix} \left|g_{1,1}\right|^2, \left|g_{2,M}\right|^2 \\ \left|g_{1,2}\right|^2, \left|g_{2,M-1}\right|^2 \\ \cdots \\ \left|g_{1,M}\right|^2, \left|g_{2,1}\right|^2 \end{bmatrix} \tag{11}$$

2) Traditional UCGD pairing scheme. The scheme focuses on maintaining a relatively uniform channel gain difference between paired users. Consider the simplest case here, pairing the user with the highest channel gain among the central users with the user with the highest channel gain among the edge users. Then, the user with the second-highest channel gain in the central user is paired with the user with the second-highest channel gain in the edge user, and so on.

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$$\begin{bmatrix} \text{User cluster 1} \\ \text{User cluster 2} \\ \cdots \\ \text{User cluster M} \end{bmatrix} = \begin{bmatrix} |g_{1,1}|^2, |g_{2,1}|^2 \\ |g_{1,2}|^2, |g_{2,2}|^2 \\ \cdots \\ |g_{1,M}|^2, |g_{2,M}|^2 \end{bmatrix} \tag{12}$$

3) Near and far pairing combined with minimum pairing distance scheme. Under the condition that user pairing scheme 1 is met, the minimum pairing distance threshold is set for the pairing of central users and edge users. If the minimum pairing distance threshold is not met, users will not be paired and traditional OMA will be used for transmission.

$$\begin{bmatrix} \text{User cluster 1} \\ \text{User cluster 2} \\ \cdots \\ \text{User cluster M} \end{bmatrix} = \begin{bmatrix} |g_{1,1}|^2, |g_{2,M}|^2 \\ |g_{1,2}|^2, |g_{2,M-1}|^2 \\ \cdots \\ |g_{1,M}|^2, |g_{2,1}|^2 \end{bmatrix} \tag{13}$$

$$\begin{bmatrix} \left| \left(|g_{1,1}|^2\right)_D - \left(|g_{2,M}|^2\right)_D \right| \geq D_{th} \\ \left| \left(|g_{1,2}|^2\right)_D - \left(|g_{2,M-1}|^2\right)_D \right| \geq D_{th} \\ \cdots \\ \left| \left(|g_{1,M}|^2\right)_D - \left(|g_{2,1}|^2\right)_D \right| \geq D_{th} \end{bmatrix} \tag{14}$$

Where, $\left| \left(|g_{1,1}|^2\right)_D - \left(|g_{2,M}|^2\right)_D \right|$ is the distance between the first user in the central user group and the M-TH user in the edge user group, and D_{th} is the minimum pairing distance threshold.

4. Classic UCGD pairing scheme combined with minimum pairing distance. Under the condition that user pairing scheme 2 is met, the minimum pairing distance threshold is set for the pairing of central users and edge users. If the minimum pairing distance threshold is not met, users will not be paired and traditional OMA is used for transmission.

$$\begin{bmatrix} \text{User cluster 1} \\ \text{User cluster 2} \\ \cdots \\ \text{User cluster M} \end{bmatrix} = \begin{bmatrix} |g_{1,1}|^2, |g_{2,1}|^2 \\ |g_{1,2}|^2, |g_{2,2}|^2 \\ \cdots \\ |g_{1,M}|^2, |g_{2,M}|^2 \end{bmatrix} \tag{15}$$

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$$\begin{bmatrix} \left| \left(\left|g_{1,1}\right|^2\right)_D - \left(\left|g_{2,1}\right|^2\right)_D \geq D_{th} \right| \\ \left| \left(\left|g_{1,2}\right|^2\right)_D - \left(\left|g_{2,2}\right|^2\right)_D \geq D_{th} \right| \\ \cdots \\ \left| \left(\left|g_{1,M}\right|^2\right)_D - \left(\left|g_{2,M}\right|^2\right)_D \geq D_{th} \right| \end{bmatrix} \tag{16}$$

Where, $\left| \left(\left|g_{1,1}\right|^2\right)_D - \left(\left|g_{2,1}\right|^2\right)_D \right|$ is the distance between the first user in the central user group and the first user in the edge user group, and D_{th} is the minimum pairing distance threshold.

3.3 Power Distribution Scheme

The uplink channel matrix G is estimated at the base station using the pilot frequency sent by the NOMA user. In order to reduce pilot pollution between each cluster, M orthogonal multiple access pilots were used to transmit between M clusters and the base station. To minimize training overhead, each user in a given group shares a non-orthogonal multiple access pilot transmission, which results in interference for users within the group. The single central user or edge user that does not meet the pairing requirement uses non-orthogonal multiple access pilot and base station transmission. This intra-group allocation method is used to balance the conflicts among the number of user nodes served simultaneously in the same time-frequency resource block, training cost and intra-group interference. The channel coherence interval (τc) is divided into two orthogonal segments, each of which is not orthogonal. The first segment with the $\tau \geq N$ symbol duration is used to transmit the user pilot. The pilot signal received at the base station can be written as:

$$Y_p = \sqrt{\tau P_u} \sum_{n=1}^{M} \sum_{k=1}^{K} g_{nk} \phi_n + N_p \tag{17}$$

Where, ϕ_n is the pilot sequence shared by users in the N-TH cluster, P_u is the pilot transmitting power at each user, and $N_p \sim CN_{M\times\tau}$ is the complex numerical additive Gaussian white noise (AWGN) matrix at BS.

According to the NOMA rationale, multiple users simultaneously send signals to the base station over the same spectrum resource, and the base station has known its channel state information (CSI), allowing for the transmission of mixed signals from different users. In order to separate overlapping signals, SIC technology is used to eliminate multi-user interference. The base station first decodes the signals of the first k(k<n) users, and the signals of the remaining (N-n) users are regarded as interference. Then the data transmission rate of the N-TH user is as follows:

$$R_n = \log_2(1 + \frac{p_n \mid g_n \mid^2}{\sum_{i=n+1}^{N} p_i \mid g_i \mid^2 + \sigma^2}) \tag{18}$$

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Energy efficiency η is the ratio of the total reachable speed of the NOMA uplink to the total power consumption:

$$\eta = \frac{\sum_{n=1}^{N} R_n}{\sum_{n=1}^{N} p_n + P_C} \tag{19}$$

P_C refers to the total power consumed by other circuit systems except the transmitted power. The optimization problem of maximization of uplink energy efficiency of NOMA system is expressed as:

$$\max_{p_n} \eta \tag{20-a}$$

$$s.t. 0 \le p_n \le p_{max} \tag{20-b}$$

$$R_n \ge R_{min}, n \in \{1, 2, \cdots, N\} \tag{20-c}$$

$$\sum_{n=1}^{N} P_{pair(i)} < B, B \in \{1, 2, \cdots, N\} \tag{20-d}$$

Where, p_{max} is the maximum transmitting power limit of user n; R_{min} is the minimum transmission rate of user n, and Formula (20-c) is to ensure that the data transmission rate of user meets the constraint conditions of the minimum transmission rate. Formula (20-d) is to ensure that the user data transmission rate meets the constraint conditions of user pairing group.

The energy efficiency maximization of the uplink of NOMA system is studied under the constraints of the user's maximum transmitting power and the user's minimum transmission rate requirements. Equation (19) shows that the objective function η of Equation (20-a) is a non-convex fractional form, which is difficult to deal with. Combined with Equation (18), the reachable rate of the uplink of NOMA system:

$$\begin{aligned} R_{sum} &= \sum_{m=1}^{M} \log_2 \left(1 + \frac{p_m |h_m|^2}{\sum_{i=2}^{M} p_i |h_i|^2 + \sigma^2}\right) = \\ & \log_2 \left(1 + \frac{p_1 |h_1|^2}{\sum_{i=2}^{M} p_i |h_i|^2 + \sigma^2}\right) \\ & + \log_2 \left(1 + \frac{p_2 |h_2|^2}{\sum_{i=3}^{M} p_i |h_i|^2 + \sigma^2}\right) + \\ & \cdots + \log_2 \left(1 + \frac{p_{M-1} |h_{M-1}|^2}{p_M |h_M|^2 + \sigma^2}\right) + \log_2 \left(1 + \frac{p_M |h_M|^2}{\sigma^2}\right) \end{aligned} \tag{21}$$

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$$
\begin{aligned}
&= \log_2\left(\frac{p_1|h_1|+\sum_{i=2}^{M}p_i|h_i|^2+\sigma^2}{\sum_{i=2}^{M}p_i|h_i|^2+\sigma^2}\times\frac{\sum_{i=2}^{M}p_i|h_i|^2+\sigma^2}{\sum_{i=3}^{M}p_i|h_i|^2+\sigma^2}\right.\\
&\left.\times\cdots\times\frac{\sum_{i=M-1}^{M}p_i|h_i|^2+\sigma^2}{p_M|h_M|^2+\sigma^2}\times\frac{p_M|h_M|^2+\sigma^2}{\sigma^2}\right)\\
&= \log_2\left(1+\frac{\sum_{m=1}^{M}p_m|h_m|^2}{\sigma^2}\right)
\end{aligned}
\tag{22}
$$

Set function:

$$
f=\log_2\left(1+\frac{\sum_{m=1}^{M}p_m|h_m|^2}{\sigma^2}\right) \tag{23}
$$

The:

$$
\frac{\partial f}{\partial p_m}=\frac{|h_m|^2}{\ln 2(\sum_{m=1}^{M}p_m|h_m|^2+\sigma^2)} \tag{24}
$$

After obtaining the partial derivative of equation (5) again, we get:

$$
\frac{\partial^2 f}{\partial^2 p_m}=-\frac{|h_m|^4}{\ln 2(\sum_{m=1}^{M}p_m|h_m|^2+\sigma^2)^2}<0 \tag{25}
$$

Therefore, the function f, namely the reachable rate Rsum of the system, is a concave function of pm, and the total power consumption of the system is an affine function. Therefore, the energy efficiency η of the uplink of NOMA system is a strictly pseudo-concave function.

Substitute equation (1) into Equation (3b),

$$
p_m|h_m|^2\geq(2^{R_{min}}-1)\left(\sum_{i=m+1}^{M}p_i|h_i|^2+\sigma^2\right) \tag{26}
$$

The energy efficiency maximization optimization problem of NOMA system uplink is equivalent to:

$$
\max_{p_m}\left[\frac{\log_2\left(1+\frac{\sum_{m=1}^{M}p_m|h_m|^2}{\sigma^2}\right)}{\sum_{m=1}^{M}p_m+p_C}\right] \tag{27-a}
$$

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$$s.t. 0 \le p_m \le p_{max} \tag{27-b}$$

$$p_m |h_m|^2 \ge (2^{R_{min}} - 1)(\sum_{i=m+1}^{M} p_i |h_i|^2 + \sigma^2), m \in \{1, 2, \cdots, M\} \tag{27-c}$$

The objective function of Equation (7) is a strictly pseudo-concave function, which is solved by Dinkelbach algorithm [11]. Assume the maximum uplink energy efficiency of NOMA system:

$$\eta^* = \frac{\log_2(1 + \frac{\sum_{m=1}^{M} p_m^* |h_m|^2}{\sigma^2})}{\sum_{m=1}^{M} p_m^* + P_C} \tag{28}$$

The:

$$\log_2(1 + \frac{\sum_{m=1}^{M} p_m^* |h_m|^2}{\sigma^2}) - \eta^*(\sum_{m=1}^{M} p_m^* + P_C) = 0 \tag{29}$$

Where, p_m^* (m= 1,2... , M) refers to the transmitting power values of M users when the uplink energy efficiency of NOMA system reaches the maximum η^*.

Set function:

$$F(\eta) = \log_2(1 + \frac{\sum_{m=1}^{M} p_m |h_m|^2}{\sigma^2}) - \eta(\sum_{m=1}^{M} p_m + P_C) \tag{30}$$

Each set of PMS corresponds to a line in the rectangular coordinate system with a non-positive slope and a non-negative longitudinal intercept. For each line, when F (η) =0, the cross-intercept is the energy efficiency η corresponding to this group of pm, at this time, η* is the optimal power of each user. Therefore, the optimization problem model for maximization of energy efficiency of NOMA uplink can be equivalent transformed into:

$$\max_{p_m} \quad F(\eta) \tag{27-a}$$

$$s.t. 0 \le p_m \le p_{max} \tag{27-b}$$

$$p_m |h_m|^2 \ge (2^{R_{min}} - 1)(\sum_{i=m+1}^{M} p_i |h_i|^2 + \sigma^2), m \in \{1, 2, \cdots, M\} \tag{27-c}$$

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Define the minimum error of equation (27-a) and (28) as α, initialize energy efficiency value η=0, find a group of pm that makes F(0) get the maximum value, substitute this group of pm into equation (27-a), find the next energy efficiency value η, until the function F (η) is less than or equal to the minimum error α, then η is the estimated value of the optimal energy efficiency η*.

4. Group Matching Algorithm based on Primary and Secondary User Distance

The total number of idle users is denoted by f, the number of users in a group is denoted by cnt, the distance between primary and secondary users is denoted by d, and the distance threshold η.

Algorithm 1	Group matching algorithm based on primary and secondary user distance
1	Initialize idle group M, Pu and Su , n = 2
2	Select Grouping mode;
3	for i = 1 to D do
	cnt = 0
4	for j = 1 to F do
5	Calculate d;
6	if d_{ij} <η&& cnt <= n
7	$Pu_i \in M$, $Su_j \in M$;
	cnt = cnt + 2;
8	end if
9	end for
10	end for
11	Output M

5. Optimal Power Iteration Algorithm

In Algorithm 2, we propose an iterative algorithm based on Dinkelbach. The following algorithm allows us to obtain the optimal solution of Pm.

Algorithm 2	Optimal power iteration algorithm
1	Initialize $\lambda > 0, \eta_u = 0$,epsilon = 10^{-3}
2	while F > epsilon
3	$P_m = \max_{p_m}[\log_2(1+\frac{\sum_{m=1}^{M} p_m \mid h_m \mid^2}{\sigma^2}) - \eta_u\left(\sum_{m=1}^{M} p_m + p_C\right)]$ s.t. $(27-b),(27-c)$
4	$F_u(\eta_u) = \log_2(1+\frac{\sum_{m=1}^{M} p_m^* \mid h_m \mid^2}{\sigma^2}) - \eta^*(\sum_{m=1}^{M} p_m^* + P_C)$

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5 $\eta_u = \log_2(1 + \frac{\sum_{m=1}^{M} p_m^* |h_m|^2}{\sigma^2}) - (\sum_{m=1}^{M} p_m^* + P_C)$

6 If $F_u(\eta_u) > \lambda$, return to step 3; otherwise, output the approximate value η_u^* of the maximum energy efficiency and the value P_m at this time

6. Simulation Results

Through simulation and analysis, the superior performance of the proposed method in the uplink communication system with primary and secondary user grouping is verified. It is assumed that the base station is located in the center of the cell, and the primary and secondary users are randomly distributed, The primary users and secondary users of the communication network in the uplink can be matched according to the distance threshold. Table 1 contains the relevant simulation parameters.

Table 1. System simulation parameters.

Parameter	Value
Number of primary users	4
Number of secondary users	4
Number of base station antennas	64
Base station coverage diameter	600m
Bandwidth	100MHz
Running times	1000
Maximum number of users in a group	2
The maximum transmit power of Users	20dBm
The minimum transmit power of Users	-20dBm
Path loss index	3.5
Noise spectral density	-140dBm/Hz
Communication scenarios	Uplink

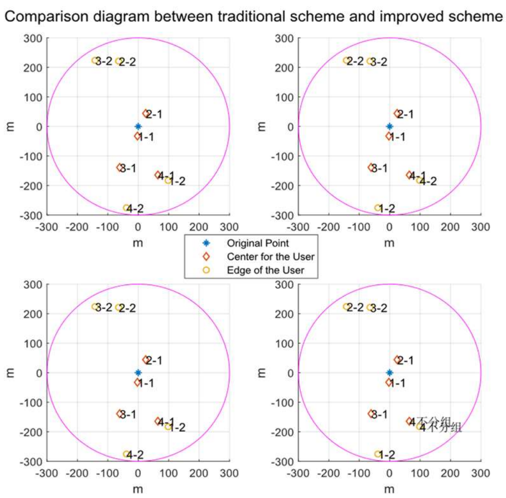

Fig. 2 Comparison diagram between traditional scheme and improved scheme

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In order to prove the effectiveness of energy efficiency maximization based on the distance between primary and secondary users, the proposed scheme is compared with two classical schemes: the traditional near-far pairing and the traditional UCGD pairing.

In Fig. 2, the horizontal and vertical axes represent the base station coverage distance, the location of the base station is represented by a blue diamond, the central user is represented by a red diamond, and the edge user is represented by a yellow circle. The top two figures are the traditional near-far pairing scheme and the traditional UCGD pairing scheme, and the bottom two corresponding figures are the improved scheme after limiting the pairing distance between the primary user and the secondary user.

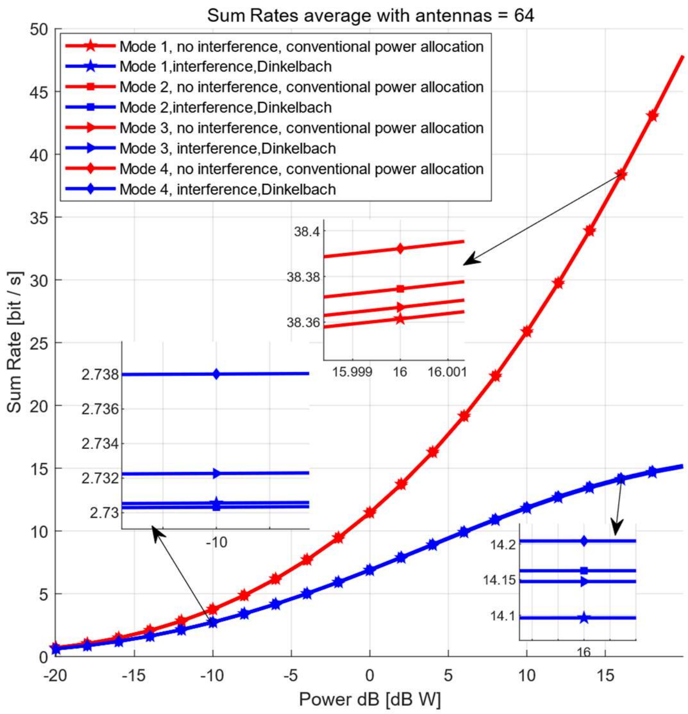

Fig. 3 Comparison of theoretical and actual communication rates of traditional and improved schemes

In Fig. 3, the horizontal axis represents the total user power, the vertical axis represents the total communication rate, and the red line is allocated by the traditional power allocation method after the primary user and the secondary user are grouped, without considering the interference situation. After grouping the primary and secondary users, the blue lines are allocated by Dinkelbach algorithm, considering the interference. Triangles and diamonds correspond to the third and fourth user pairing schemes proposed in this paper, respectively. In addition, we observe that although the total communication rate of the four user grouping pairing methods after optimized by Dinkelbach algorithm is close, the overall performance of the improved UCGD scheme using the grouping method based on the distance between primary and secondary users is better than the other three schemes. The improved near-far pairing scheme is better than the traditional near-far pairing and UCGD scheme at low power, but it is slightly weaker than the traditional UCGD scheme at high power. Experimental results show that the overall performance of the improved near-far pairing scheme and UCGD scheme is better than other traditional pairing schemes.

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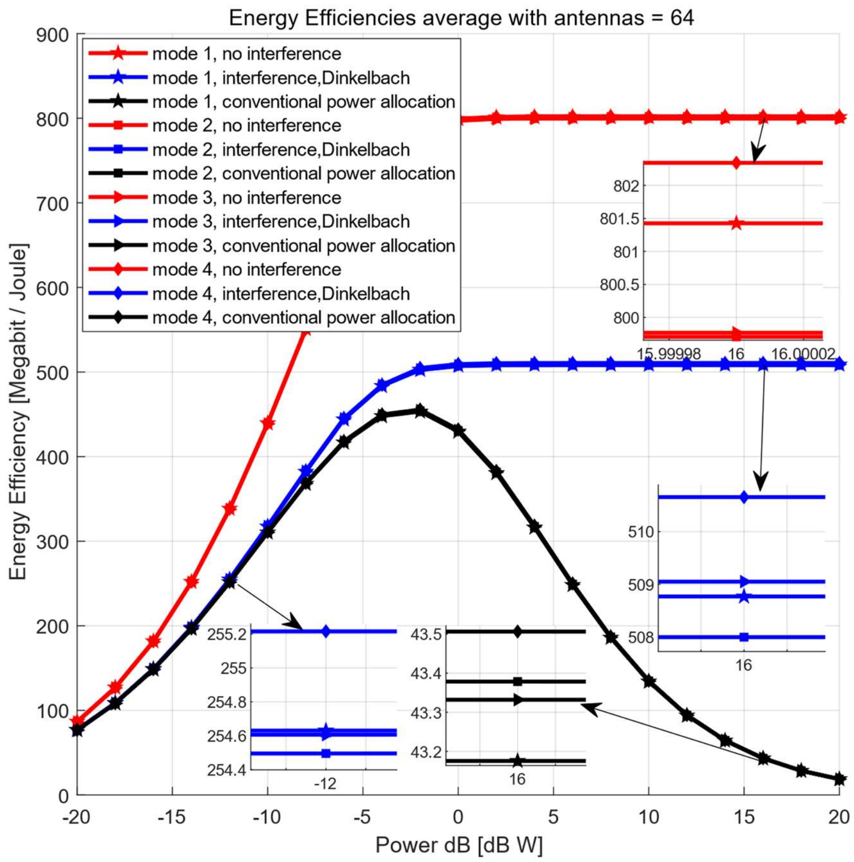

Fig. 4 Comparison diagram of theoretical and practical communication energy efficiency of traditional and improved schemes

In FIG. 4, we study the relationship between EE and transmit power. It can be observed that when the circuit power grows from -20 dBm to 0 dBm, the EE increases as the transmit power increases. When the circuit power increases from 0 dBm to 20 dBm, the EE of the four packet modes optimized by Dinkelbach algorithm without considering interference is about 800Megabit/joule. The EE of the four packet modes optimized by Dinkelbach algorithm considering interference is all 510Megabit/joule. In addition, the EE of the four packet modes optimized by traditional algorithm without considering interference decreases exponentially.

Considering the actual situation, we mainly observe the EE value changes of the four grouping modes optimized by Dinkelbach algorithm considering the interference situation. In addition, we observe that although the EE values of the four user grouping and pairing methods optimized by Dinkelbach algorithm are similar, However, the overall performance of the improved UCGD scheme based on the distance grouping method of primary and secondary users and the improved near-far pairing scheme is better than the other two traditional schemes. The modified near-far pairing scheme is lower than the conventional near-far pairing scheme at low power, but slightly higher than the conventional near-far pairing scheme and the conventional UCGD scheme at high power. Experimental results show that the overall performance of the improved near-far pairing scheme and UCGD scheme is better than other traditional pairing schemes.

7. Conclusion

In this paper, the power resource allocation problem of the uplink of NOMA system is studied, and the multi-user distance group energy efficiency optimization model of the uplink of NOMA system is established for the first time. Then Dinkelbach algorithm is applied to solve the optimization problem, and finally the global optimal solution of user power which maximizes the energy efficiency of the system is obtained. The simulation results show that: Compared with the user power allocation algorithm which takes the spectrum efficiency as the performance index, the Dinkelbach algorithm proposed in this paper and the distance grouping limit, although the spectrum efficiency of the NOMA system uplink is reduced, but the energy efficiency of the system is improved, and according to the distance grouping mode, the energy efficiency of the system is higher than the traditional grouping mode. Future research would benefit from a focus on energy optimization in the way users are grouped.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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