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Research on Interference Coordination Optimization Strategy for User Fairness in NOMA Heterogeneous Networks

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Abstract: In order to comprehensively improve the performance of edge users in heterogeneous cellular networks and the fairness of network users, a downlink interference coordination optimization strategy in heterogeneous cellular networks with non-orthogonal multiple access (NOMA) based on the cell range expansion (CRE) and the almost blank subframe (ABS) technology is proposed. Different from the traditional interference coordination strategy, a NOMA user pairing scheme combined with ABS technology and a dynamic NOMA power allocation scheme are designed to maximize the network fairness based on the optimized throughput of the edge users. The simulation results show that the proposed optimization strategy can balance the performance of network users more effectively to improve the throughput of edge users and network fairness than other NOMA user pairing and power allocation algorithms without the complexity being increased.

Keywords: heterogeneous cellular networks; fairness; non-orthogonal multiple access; cell range expansion; almost blank subframe; user pairing

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1. Introduction

Deploying picocells in traditional macrocells to build hierarchical heterogeneous networks (HetNets) can effectively solve problems, such as uneven distribution of users and insufficient coverage of hotspot areas [1]. Due to the different deployment methods of different networks in HetNets, there are some problems with co-tier interference and cross-tier interference in HetNets. Therefore, inter-cell interference coordination technology is one of the hot spots in the research of heterogeneous cellular networks. Therefore, inter-cell interference coordination technology is one of the hotspots in the research of heterogeneous cellular networks. Among them, enhanced inter-cell interference coordination (eICIC) [2] includes cell range expansion (CRE) and almost blank subframe (ABS) and has been widely used in two-tier heterogeneous cellular networks.

Firstly, because the transmit power of the macrocell base station (MBS) is much larger than that of the picocell base station (PBS) in the downlink of HetNets, most users choose to access the MBS for the larger transmit power; which will cause unbalanced load distribution. Secondly, the macrocell users who are located near the picocell and are far away from the MBS need to increase transmit power to communicate with the MBS in the uplink of HetNets. At the same time, this will cause serious uplink interference in the PBS. In order to solve the above problems, CRE technology [2] has been proposed in 3GPP. The basic principle is to add a positive bias value on the basis of the reference signal receiving power (RSRP) from the PBS so that more macrocell users are off-loaded to the picocell to balance the network load and reduce the uplink interference. However, the users who access the PBS through CRE will suffer severe interference from the MBS and the downlink performance of the network will be affected. ABS technology [2] is effective in addressing this interference problem. The basic principle is that the MBS stops transmission in a specific subframe to protect the users which suffer severe interference from the MBS. Then these users can communicate in a specific subframe to reduce the interference from the tier of macrocell. The reference [3] realizes the self-optimized networking based on CRE and ABS and evaluates the gains of real network data. Moreover, the eICIC technology has been combined with coordinated multipoint (CoMP) in [4] to satisfy the requirement of the users. A novel joint user association with the eICIC scheme [5] was proposed to solve the max-min fairness optimization problem by the optimal ABS ratio. Moreover, a novel user throughput estimation method [6] where ABS and a proportional fairness scheduler are applied was proposed to maximize cell user throughput by adjusting the ABS ratio. The interaction among the base stations was modeled as a near-potential game [7] and uses distributed learning algorithms to achieve better load balancing. In [8], the author performed the eICIC configuration with multiple coexisting services and designed an optimization algorithm based on the alternating direction method which adapts CRE bias at the service layer and the ABS ratio at the base station (BS) layer. Moreover, an adaptive ABS configuration scheme [9] was proposed to dynamically match the real-time users and combines the power control of MBS to improve the performance of edge users. Because of the downlink/uplink decoupling, a novel method for the load balancing of downlink and uplink [10] was proposed to improve the throughput and rate gain based on ABS configuration. The energy efficiency (EE) with interference coordination in HetNets has been considered in [11] and a max-min energy efficient algorithm with eICIC was proposed to improve the performance of the network. Moreover, reference [12] proposed an energy efficient optimized strategy to balance the load, reduce the interference and increase the system EE and fairness at the same time.

In recent years, the combination of non-orthogonal multiple access (NOMA) and HetNets has received a considerable amount of attention. Power-domain NOMA [13] allocates different power to different users according to their channel quality and transmits at the same time-frequency-code resources. In order to distinguish different users, successive interference cancellation (SIC) technology is used at the receivers. Consequently, compared with OMA, NOMA can significantly enhance spectral efficiency at the cost of increased receiver complexity. In [14], the author evaluated the combination of NOMA and HetNets by capacity gain and the impact of different user pairing methods was taken into consideration. That demonstrates the potential of NOMA HetNets in the context of the high data demand of networks. Moreover, the performance of NOMA and OMA in HetNets is investigated in terms of the coverage probability, achievable rate and energy efficiency in [15,16]. The problem of power allocation of MBS and PBS [17] and the problem of user pairing (UP) and power allocation (PA) [18] were proposed to improve the throughput of each user. In addition, energy efficiency [19–21] and fairness [22,23] are also a hotspot for NOMA HetNets. Compared with non-NOMA HetNets, co-tier interference, cross-tier interference and NOMA co-channel interference make the interference coordination more complex in NOMA HetNets. Interference management based on compressive sensing (CS) [24] and interference management based on interference alignment and coordinated beamforming (IA-CB) [25] were proposed. In [26], A user scheduling scheme and distributed power control algorithm were proposed to improve the spectral efficiency and outage performance. Moreover, the interference coordination strategy of the frequency-domain [27,28] and the strategy of the space-domain [29,30] have been considered.

Most of the abovementioned research focuses on interference coordination of NOMA HetNets; however, there is a lack of interference coordination optimization strategy for the time-domain of NOMA HetNets. Therefore, inspired by current research, this paper takes two-tier HetNets with an uneven distribution of users into consideration where CRE and ABS are applied to interference coordination. A novel user pairing scheme is proposed and the condition that the throughput of the user does not drop as the transmission subframe switch is derived. Moreover, we derive the expression of the dynamic power allocation factor according to the condition of the smallest difference between the users of the same pair. Moreover, the proposed user pairing scheme can perform dynamically based on the

ABS ratio and has better performance than other user pairing schemes of similar complexity. Finally, we take the idea of game theory to reduce the computational complexity of the joint optimization algorithm of adaptive CRE and ABS. Moreover, the proposed interference coordination optimization strategy can effectively manage interference and the network with the proposed strategy and has better performance than a network with other strategies.

The remainder of the paper is structured as follows: In Section 2, the system model is constructed. Section 3 presents the entire interference coordination optimization strategy. Simulation and numerical results are given and analyzed in Section 4, and the conclusion is summarized in Section 5.

2. System Model

As shown in Figure 1, a downlink model of two-tier heterogeneous networks is considered in this paper. The first tier includes one MBS and the maximum transmit power of the MBS is $P_{\mathrm{M}}^{\max}$. The MBS is configured with a sector antenna array and the coverage area is divided into three macrocells that are 120 degrees from each other. In the second tier, there are N_{P} PBSs whose maximum transmit power is $P_{\mathrm{P}}^{\max}$ randomly distributed in the coverage of macrocells. It is assumed that the number of picocells in each macrocell is the same. In order to improve spectral efficiency, the MBS and the PBSs share the same spectral resources. The users of each BS use NOMA or full power mode to communicate, and the users who transmit in NOMA mode recover the signals at the receivers through SIC technology.

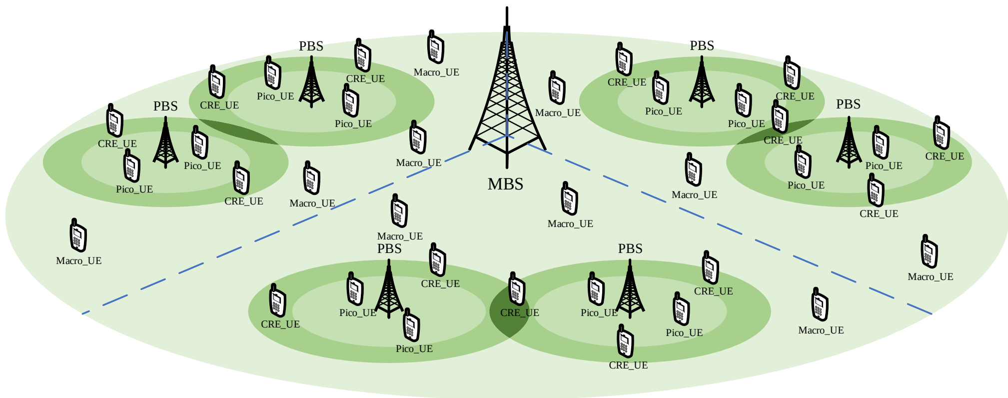


Figure 1. System model.

In this model, a downlink NOMA HetNets which consists of one MBS denoted by $b = 1$ and $N_{\mathrm{B}} - 1$ PBSs denoted by $b = 2, 3, \ldots, N_{\mathrm{B}}$ is considered. Let the number of users of BS b is denoted by N_{U}^{b}. Moreover, each user can be served by only one BS and perfect channel state information is considered. The total available system bandwidth is denoted by B and is divided into N_{SC}^{b} ($2N_{\mathrm{SC}}^{b} \geq N_{\mathrm{U}}^{b}$) orthogonal subchannels with the bandwidth B/N_{SC}^{b} by BS b. Let, $n = 1, 2, \ldots, N_{\mathrm{SC}}^{b}$ represent the set of subchannels of BS b. We assume that the greatest number of NOMA users on each subchannel is 2, and the user with the worst signal to interference-plus-noise ratio (SINR) will transmit with full power on the subchannel if the number of users of BS is odd. We assumed that the weak user is denoted by $u = 1$ and the strong user is denoted by $u = 2$ on the subchannel n of BS b.

The NOMA superimposed signal transmitted by the subchannel n of BS b can be expressed as:

$$x_b^n = \sqrt{\alpha_b^n} s_{1,b}^n + \sqrt{\left(1 - \alpha_b^n\right)} s_{2,b}^n, \tag{1}$$

where $s_{1,b}^n$ and $s_{2,b}^n$ are the signals of weak users and strong users. α_b^n is the power allocation factor of the subchannel n of the BS b and $1/2 < \alpha_b^n < 1$ since the BS needs to allocate more power for weak users. The received signals of two users on the subchannel n of BS b are given by:

$$y_{u,b}^{n} = h_{u,b}^{n}\sqrt{p_{b}^{n}}x_{b}^{n} + \sum_{b'=1,b'\neq b}^{N_{\mathrm{B}}} h_{u,b'}^{n}\sqrt{p_{b'}^{n}}x_{b'}^{n} + \omega_{u,b'}^{n} \tag{2}$$

where $h_{u,b}^{n}$ represents the channel gain between BS b and user u on the subchannel n, including the channel gain of large-scale fading and small-scale Rayleigh fading. p_{b}^{n} represents the transmit power of BS b on the subchannel n and $\omega_{u,b}^{n} \sim CN\left(0, \sigma^{2}B/N_{\mathrm{SC}}^{b}\right)$ represents the additive white Gaussian noise (AWGN); the mean is zero and the variance is $\sigma^{2}B/N_{\mathrm{SC}}^{b}$ of BS b on the subchannel n. $\sum_{b'=1,b'\neq b}^{N_{\mathrm{B}}} h_{u,b'}^{n}\sqrt{p_{b'}^{n}}x_{b'}^{n}$ represents the aggregate interference from other BSs, including co-tier interference and cross-tier interference. It is assumed that a strong user can successfully demodulate the signal of a weak user and that means a strong user can cancel the interference from the signal of a weak user in the same NOMA group. The transmission rate of two NOMA users on the subchannel n of BS b is given by:

$$R_{1,b}^{n} = \frac{B}{N_{\mathrm{SC}}^{b}}\log_{2}\left(1 + \frac{\left|h_{1,b}^{n}\right|^{2}\alpha_{b}^{n}p_{b}^{n}}{\left|h_{1,b}^{n}\right|^{2}\left(1-\alpha_{b}^{n}\right)p_{b}^{n} + \sum\limits_{b'=1,b'\neq b}^{N_{\mathrm{B}}}\left|h_{1,b'}^{n}\right|^{2}p_{b'}^{n} + \frac{\sigma^{2}B}{N_{\mathrm{SC}}^{b}}}\right), \tag{3}$$

$$R_{2,b}^{n} = \frac{B}{N_{\mathrm{SC}}^{b}}\log_{2}\left(1 + \frac{\left|h_{2,b}^{n}\right|^{2}\left(1-\alpha_{b}^{n}\right)p_{b}^{n}}{\sum\limits_{b'=1,b'\neq b}^{N_{\mathrm{B}}}\left|h_{2,b'}^{n}\right|^{2}p_{b'}^{n} + \frac{\sigma^{2}B}{N_{\mathrm{SC}}^{b}}}\right). \tag{4}$$

If there is only one user u on the subchannel n of BS b, the user will transmit in full power mode, and the transmission rate is:

$$R_{u,b}^{n} = \frac{B}{N_{\mathrm{SC}}^{b}}\log_{2}\left(1 + \frac{\left|h_{u,b}^{n}\right|^{2}p_{b}^{n}}{\sum\limits_{b'=1,b'\neq b}^{N_{\mathrm{B}}}\left|h_{u,b'}^{n}\right|^{2}p_{b'}^{n} + \frac{\sigma^{2}B}{N_{\mathrm{SC}}^{b}}}\right). \tag{5}$$

3. Interference Coordination Scheme Analysis

3.1. CRE and ABS

The coverage areas of PBSs are not only limited by the transmit power of PBSs, but also limited by the cross-tier interference of MBS. So, there are only a few users near the PBSs that can be served by PBSs. Moreover, Cell range expansion (CRE) is a cell access selection strategy with a positive bias value based on the traditional cell access selection strategy of maximum reference signal receiving power (RSRP). The terminals add a positive bias value to the downlink measurement of RSRP of picocells before they choose to access BS to expand the coverage of the picocells and off-load part of the macro users to the picocells. Cell access selection strategy is given as:

$$Cell\_ID_{access} = \underset{b}{\operatorname{argmax}}\{RSRP_{b} + bias_{b}\}, \tag{6}$$

where

$$\begin{cases} bias_{b} = 0, if\ b\ is\ MBS \\ bias_{b} > 0, if\ b\ is\ PBS \end{cases}. \tag{7}$$

Due to the positive bias value of PBS, there are more macro users off-loaded to the picocells. An important benefit of CRE is that the spectral resources can be more uniformly distributed to the network users because of the similar number of users and the same spectral resources of BSs. The users who access the PBS through CRE will suffer severe cross-tier interference from MBS; the almost blank subframe (ABS) of the time-domain inter-cell interference coordination (ICIC) needs to be applied in HetNets. ABS is a subframe where MBS only transmits cell common reference signals (CRS) and other necessary signals. Therefore, the users will experience close to zero cross-tier interference from MBS in subframes where MBS uses ABS. The basic principle of ABS is illustrated in Figure 2.

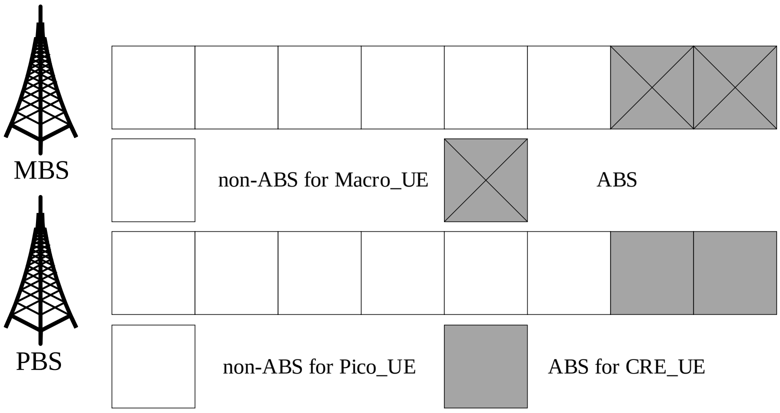


Figure 2. Basic principle of ABS.

In the networks, there is only one type of user of MBS which is called Macro_UE and is scheduled during non-ABS. Moreover, PBS has two types of users named Pico_UE and CRE_UE, respectively. The Pico_UEs are scheduled during non-ABS while the CRE_UEs are scheduled during ABS. This means that the CRE_UEs of picocells are protected from cross-tier interference from MBS.

The CRE scheme off-loads some macro users to the picocells to achieve load balancing while the ABS scheme alleviates the severe cross-tier interference from MBS that will effectively improve the performance of the networks.

3.2. Optimization Strategy for User Fairness

Let, $m = 1, 2, \ldots, N_{\mathrm{M}}$ represent the set of macrocells; the number of macrocells is denoted by N_{M}. The set of all edge users of the macrocell m is presented by U_m^{Edge} and the number of edge users of the macrocell m is denoted by $N_m^{\mathrm{U,Edge}}$. Moreover, the set of all edge users includes the set of macro edge users, the set of general pico edge users and the set of CRE edge users which are presented by $U_m^{\mathrm{M,Edge}}$, $U_m^{\mathrm{P,Edge}}$ and $U_m^{\mathrm{CRE,Edge}}$, respectively. The number of users in the above set is denoted by $N_m^{\mathrm{M,Edge}}$, $N_m^{\mathrm{P,Edge}}$ and $N_m^{\mathrm{CRE,Edge}}$, respectively, and the total number of edge users in the networks is denoted by $N_{\mathrm{U}}^{\mathrm{Edge}}$.

For the HetNets, the average throughput of edge users is an important metric [9] for judging the advantage of the performance of the networks. To a certain extent, the performance of edge users can reflect the user fairness of the network. Therefore, the joint optimization strategy of the adaptive CRE and ABS designed in this paper considers the performance requirements of the edge users of the networks. The adaptive mode means that the ABS ratio value of each macrocell can be different while the CRE bias value of each picocell can also be different and the optimal result is achieved according to the load situation in the networks. Therefore, the optimal ABS ratio value is denoted by

$\boldsymbol{\xi} = \left[\xi_1, \xi_2, \ldots, \xi_{N_{\mathrm{M}}}\right]$ and the optimal CRE bias value is denoted by $\boldsymbol{\eta} = \left[\eta_2, \eta_3, \ldots, \eta_{N_{\mathrm{B}}}\right]$. The average throughput function of edge users of the HetNets is given by:

$$T(\boldsymbol{\xi}, \boldsymbol{\eta}) = \frac{\sum\limits_{m=1}^{N_{\mathrm{M}}} \sum\limits_{u=1}^{N_m^{\mathrm{U,Edge}}} C_{m,u}^{\mathrm{Edge}}}{N_{\mathrm{U}}^{\mathrm{Edge}}}, \tag{8}$$

where

$$N_{\mathrm{U}}^{\mathrm{Edge}} = \sum_{m=1}^{N_{\mathrm{M}}} \left(N_m^{\mathrm{M,Edge}} + N_m^{\mathrm{P,Edge}} + N_m^{\mathrm{CRE,Edge}}\right), \tag{9}$$

$$C_{m,u}^{\mathrm{Edge}} = \begin{cases} (1-\xi_m) R_{m,u}^{\mathrm{Edge}}, u \in \left(U_m^{\mathrm{M,Edge}} \cup U_m^{\mathrm{P,Edge}}\right) \\ \xi_m R_{m,u}^{\mathrm{Edge}}, u \in N_m^{\mathrm{CRE,Edge}} \end{cases}. \tag{10}$$

In (10), ξ_m represents the ABS ratio value of the macrocell m, while the $R_{m,u}^{\mathrm{Edge}}$ represents the transmission rate of the user u of the macrocell m and can be found by (3)–(5) according to the transmission mode and type of user. $N_m^{\mathrm{M,Edge}}$, $N_m^{\mathrm{P,Edge}}$ and $N_m^{\mathrm{CRE,Edge}}$ depends on the CRE bias value η because more and more macro users are off-loaded to picocells as the CRE bias values increase and that will lead to less available resources distributed by the CRE edge users. Thus, the group of network edge users will mainly consist of a part of CRE edge users and $N_m^{\mathrm{M,Edge}}$ reduces and $N_m^{\mathrm{CRE,Edge}}$ increases at this time. The objective function and the maximization problem can be expressed as:

$$\begin{aligned} & \max T(\boldsymbol{\xi}, \boldsymbol{\eta}) \\ \text{s.t.} \boldsymbol{C}_1 \quad & : 0 \leq \xi_m \leq 1, m = 1, 2, \ldots, N_{\mathrm{M}}, \\ \boldsymbol{C}_2 \quad & : \eta_b \geq 0, b = 2, 3, \ldots, N_{\mathrm{B}}, \\ \boldsymbol{C}_3 \quad & : \sum_{n=1}^{N_{\mathrm{SC}}^b} p_b^n \leq \begin{cases} P_{\mathrm{M}}^{\max}, b = 1 \\ P_{\mathrm{P}}^{\max}, b \neq 1 \end{cases}, \\ \boldsymbol{C}_4 \quad & : 0.5 < \alpha_b^n < 1, b = 1, 2, \ldots, N_{\mathrm{B}}, n = 1, 2, \ldots, N_{\mathrm{SC}}^b, \end{aligned} \tag{11}$$

where $\boldsymbol{C}_1$ and $\boldsymbol{C}_2$ can guarantee the range of the ABS ratio value and CRE bias value. $\boldsymbol{C}_3$ denotes the overall transmit power of each subchannel below a maximum power threshold and $\boldsymbol{C}_4$ guarantees that the transmit power of a weak user is greater than that of a strong use on the same subchannel of the same BS.

On the other hand, in order to evaluate the user fairness in NOMA HetNets, Jain's fairness index (JFI) is applied as a measurement of network fairness. JFI is one of the commonly used fairness metrics for wireless networks [15] and can be expressed as:

$$F(\boldsymbol{\xi}, \boldsymbol{\eta}) = \frac{\left(\sum\limits_{u=1}^{N_{\mathrm{U}}} C_u\right)^2}{N_{\mathrm{U}} \sum\limits_{u=1}^{N_{\mathrm{U}}} (C_u)^2}, \tag{12}$$

where the total number of users of the networks is denoted by N_{U} and the throughput of the user u is denoted by C_u. The larger the value of F is, the smaller the difference between the performance of user throughput is. While the performance of user throughput is consistent, the value of F will be 1.

Energy efficiency [11] is also one of the metrics for evaluating network performance, the expression of EE is given as:

$$EE(\boldsymbol{\xi},\boldsymbol{\eta}) = \frac{\sum\limits_{u=1}^{N_{\mathrm{U}}} C_u}{\sum\limits_{m=1}^{N_{\mathrm{M}}} \left(\xi_m P_{\mathrm{M}}^{\mathrm{max}}\right) + P_{\mathrm{M}}^{\mathrm{sta}} + \sum\limits_{b=2}^{N_{\mathrm{B}}} \left(P_{\mathrm{P}}^{\mathrm{max}} + P_{\mathrm{P}}^{\mathrm{sta}}\right)}, \tag{13}$$

where $P_{\mathrm{M}}^{\mathrm{sta}}$ and $P_{\mathrm{P}}^{\mathrm{sta}}$ is the static power consumed by the hardware circuit. Because the MBS is silent during ABS, the power consumption of MBS in the macrocell m can be expressed as $\xi_m P_{\mathrm{M}}^{\mathrm{max}}$.

3.3. User Pairing Scheme Combined with ABS

Aiming at the problem of different channel quality requirements in NOMA networks, user pairing is a necessary method in NOMA HetNets. Due to the difference in transmit power and coverage of base stations in heterogeneous networks, the traditional user pairing is not suitable for the network and this paper proposes a novel NOMA user pairing algorithm combined with ABS technology. Firstly, the users are classified by different types of transmission subframes. Secondly, under the condition that the throughput of the user does not drop as the transmission subframe is switched, the transmission subframe of users who transmit during non-ABS can be dynamically switched from non-ABS to ABS according to the ABS ratio. Finally, user pairing is performed in different types of transmission subframes based on the SINR of users and the user of the lowest SINR is paired with the user of the highest SINR in order to maximize the improvement of the throughput of the weak user in the pair.

Due to different ABS ratios, users have different throughput in different types of transmission subframes. The essence of dynamically pairing users according to ABS ratio is to make some users with poor transmission performance during non-ABS transmit during ABS while the ABS resources are sufficient. Moreover, the throughput of each user can be balanced. Since the users who transmit during non-ABS are seriously interfered with by the MBS, the case of assigning these users to non-ABS for transmission is not considered. In addition, since the users with poor transmission performance during non-ABS are generally weak users, it is possible for the users to be strong users or weak users if they are assigned to transmit during ABS. For convenience, the throughput expression of weak users is taken to constitute the condition that the throughput of the user does not drop as the transmission subframe switches, it can be expressed as:

$$\begin{aligned} &\frac{(1-\xi)B}{N_{\mathrm{SC\_nonABS,before}}^{b}} \log_2\left(1 + \frac{\left|h_{u,b}\right|^2 \alpha p}{\left|h_{u,b}\right|^2 (1-\alpha) p + \sum\limits_{b'=1,b'\neq b}^{N_B} \left|h_{u,b'}\right|^2 p_{b'} + \frac{\sigma^2 B}{N_{\mathrm{SC\_nonABS,before}}^{b}}}\right) \\ &< \frac{\xi B}{N_{\mathrm{SC\_ABS,after}}^{b}} \log_2\left(1 + \frac{\left|h_{u,b}\right|^2 \alpha' p'}{\left|h_{u,b}\right|^2 (1-\alpha') p' + \sum\limits_{b'=2,b'\neq b}^{N_B} \left|h_{u,b'}\right|^2 p_{b'} + \frac{\sigma^2 B}{N_{SC\_ABS,after}^{b}}}\right), \end{aligned} \tag{14}$$

where ξ represents the ABS ratio and the power allocation factor of the user which before and after the transmission subframe switching are denoted by α and α'. The power allocated for the channel of the user and the number of channels before and after switching are denoted by p, $N_{\mathrm{SC\_nonABS,before}}^{b}$, p' and $N_{\mathrm{SC\_ABS,after}}^{b}$. Since the subchannels are assigned the same power in this paper, the product of the subchannel power and the number of subchannels is the total transmit power of the base station. Let, P_b represent the transmit power of the BS b. Since the left-side and right-side of the inequality (13) are monotonically increasing functions of the power allocation factor and the increment of the right-side is larger than that of the left-side as the power allocation factor increases, we assume that power allocation factors before and after switching take the minimum value to achieve a relatively reasonable result, i.e., $\alpha = \alpha' = 0.5$. Since each subchannel can accommodate at most two NOMA users, it is assumed that there are as many NOMA user pairs as possible in the network and then $N^b_{\text{SC\_nonABS,before}} = \left\lceil N^b_{\text{U\_nonABS,before}}/2 \right\rceil$, $N^b_{\text{SC\_ABS,after}} = \left\lceil \left(N^b_{\text{U\_ABS,before}} + 1 \right)/2 \right\rceil$, where $\lceil \cdot \rceil$ represents the ceiling operation.$N^b_{\text{U\_nonABS,before}}$ and $N^b_{\text{U\_ABS,before}}$ represents the number of users that transmit during non-ABS and ABS before switching to the current user. Then the inequality can be rewritten as

$$\frac{\left\lceil \left(N^b_{\text{U\_ABS,before}} + 1 \right)/2 \right\rceil}{\left\lceil N^b_{\text{U\_nonABS,before}}/2 \right\rceil} < \frac{\xi \log_2 \left(1 + \frac{\frac{1}{2}\left|h_{u,b}\right|^2 P_b}{\frac{1}{2}\left|h_{u,b}\right|^2 P_b + \sum\limits_{b'=2, b' \neq b}^{N_B} \left|h_{u,b'}\right|^2 P_{b'} + \sigma^2 B} \right)}{(1-\xi) \log_2 \left(1 + \frac{\frac{1}{2}\left|h_{u,b}\right|^2 P_b}{\left|h_{u,1}\right|^2 P_1 + \frac{1}{2}\left|h_{u,b}\right|^2 P_b + \sum\limits_{b'=2, b' \neq b}^{N_B} \left|h_{u,b'}\right|^2 P_{b'} + \sigma^2 B} \right)}. \tag{15}$$

The right-side of the inequality is:

$$SW(u, b, \xi) = \frac{\xi \log_2 \left(1 + \frac{\frac{1}{2}\left|h_{u,b}\right|^2 P_b}{\frac{1}{2}\left|h_{u,b}\right|^2 P_b + \sum\limits_{b'=2, b' \neq b}^{N_B} \left|h_{u,b'}\right|^2 P_{b'} + \sigma^2 B} \right)}{(1-\xi) \log_2 \left(1 + \frac{\frac{1}{2}\left|h_{u,b}\right|^2 P_b}{\left|h_{u,1}\right|^2 P_1 + \frac{1}{2}\left|h_{u,b}\right|^2 P_b + \sum\limits_{b'=2, b' \neq b}^{N_B} \left|h_{u,b'}\right|^2 P_{b'} + \sigma^2 B} \right)}. \tag{16}$$

Therefore, $SW(u, b, \xi) > \left\lceil \left(N^b_{\text{U\_ABS,before}} + 1 \right)/2 \right\rceil / \left\lceil N^b_{\text{U\_nonABS,before}}/2 \right\rceil$ can be used as the condition that the throughput of the user does not drop as the transmission subframe switches. On the other hand, $SW(u, b, \xi)$ also represents the priority of the user switching. It can be seen from the expression that the user with severe cross-tier interference has higher priority when the co-tier interference is constant.

While the user switching is finished, user pairing is performed in different types of transmission subframes based on the SINR of users rather than channel gain. The SINR of users is calculated by the maximum transmit power and then the user of the lowest SINR is paired with the user of the highest SINR. The user pairing algorithm is shown in Algorithm 1.

Algorithm 1 User Pairing Algorithm

STEP1:	Initialize: the ABS ratio of macrocell where BS $b (b \neq 1)$ is located is ξ, user pairing table $\boldsymbol{U}_{\text{pair}} = [\,]$.
STEP2:	According to the user access situation of the BS b, users are divided into $\boldsymbol{U}_{\text{nonABS}}$ whose user transmit during non-ABS and $\boldsymbol{U}_{\text{ABS}}$ whose user transmit during ABS and the number of two sets are $N^b_{\text{U\_nonABS,before}}$ and $N^b_{\text{U\_ABS,before}}$.
STEP3:	For each user in $\boldsymbol{U}_{\text{nonABS}}$, calculate formula (15) to obtain the matrix $\boldsymbol{SW}$ of user switching condition and sort in descending order.
STEP4:	Traverse the users of $\boldsymbol{SW}$ from the beginning, if the formula (14) is satisfied, the user will be assigned to $\boldsymbol{U}_{\text{ABS}}$ and update $N^b_{\text{U\_nonABS,before}}$ and $N^b_{\text{U\_ABS,before}}$, otherwise jump out of the traversal.
STEP5:	The SINR of users in $\boldsymbol{U}_{\text{nonABS}}$ and $\boldsymbol{U}_{\text{ABS}}$ are separately calculated and the user pairing is performed in each set.

STEP6:	If the number of users in the user set is an odd number, the user with the worst SINR will be formed into a separate user pair to join in $\boldsymbol{U}_{\text{pair}}$, and the remaining users will be paired one by one to join in $\boldsymbol{U}_{\text{pair}}$ according to the principle that the user of the lowest SINR is paired with the user of the highest SINR.
STEP7:	Return $\boldsymbol{U}_{\text{pair}}$.

3.4. Dynamic Power Allocation Scheme

While the user pairing is completed, the problem of power allocation between users on the same channel needs to be considered. This paper takes a dynamic power allocation scheme. Since this paper considers maximizing the average throughput of edge users, the difference between the SINR of users in the same pair should be as small as possible in order to improve the throughput performance of edge users. The SINR of users in the same pair transmitted during non-ABS can be expressed as:

$$\gamma_1 = \frac{|h_1|^2 \alpha p_b}{|h_1|^2 (1-\alpha) p_b + \sum\limits_{b'=1, b' \neq b}^{N_{\text{B}}} |h_{1,b'}|^2 p_{b'} + \frac{\sigma^2 B}{N_{\text{SC}}}}, \tag{17}$$

$$\gamma_2 = \frac{|h_2|^2 (1-\alpha) p_b}{\sum\limits_{b'=1, b' \neq b}^{N_{\text{B}}} |h_{2,b'}|^2 p_{b'} + \frac{\sigma^2 B}{N_{\text{SC}}}}, \tag{18}$$

where α is the power allocation factor of a weak user in the same pair of users, and $0.5 < \alpha < 1$. The power optimization problem is expressed as:

$$\begin{gathered} \min_{\alpha} \left| \frac{|h_1|^2 \alpha p_b}{|h_1|^2 (1-\alpha) p_b + \sum\limits_{b'=1, b' \neq b}^{N_{\text{B}}} |h_{1,b'}|^2 p_{b'} + \frac{\sigma^2 B}{N_{\text{SC}}}} - \frac{|h_2|^2 (1-\alpha) p_b}{\sum\limits_{b'=1, b' \neq b}^{N_{\text{B}}} |h_{2,b'}|^2 p_{b'} + \frac{\sigma^2 B}{N_{\text{SC}}}} \right|, \\ s.t.\ \gamma_1 \geq \gamma_{\text{TH}} \\ \gamma_2 \geq \gamma_{\text{TH}} \\ 0.5 < \alpha < 1 \end{gathered} \tag{19}$$

where γ_{TH} represents the threshold of the SINR of the user. Let $PA(\alpha) = \gamma_1 - \gamma_2$, and $d(PA(\alpha))/d(\alpha) > 0$. So, $PA(\alpha)$ is a monotonically increasing function and there is only one minimum point in $|PA(\alpha)|$. Let $PA(\alpha) = 0$,

$$|h_1|^2 \alpha P_b \left(\sum_{b'=1, b' \neq b}^{N_{\text{B}}} |h_{2,b'}|^2 P_{b'} + \sigma^2 B \right) = |h_2|^2 (1-\alpha) P_b \left(|h_1|^2 (1-\alpha) P_b + \sum_{b'=1, b' \neq b}^{N_{\text{B}}} |h_{1,b'}|^2 P_{b'} + \sigma^2 B \right). \tag{20}$$

Let, $S_u = |h_u|^2 P_b$, $IN_u = \sum\limits_{b'=1, b' \neq b}^{N_{\text{B}}} |h_{u,b'}|^2 P_{b'} + \sigma^2 B$. Then the Formula (19) can be rewritten as:

$$\alpha^2 - \left(2 + \frac{IN_1}{S_1} + \frac{IN_2}{S_2} \right) \alpha + 1 + \frac{IN_1}{S_1} = 0, \tag{21}$$

$$\alpha_0 = \frac{\left(2 + \frac{IN_1}{S_1} + \frac{IN_2}{S_2} \right) - \sqrt{\left(2 + \frac{IN_1}{S_1} + \frac{IN_2}{S_2} \right)^2 - 4\left(1 + \frac{IN_1}{S_1} \right)}}{2}. \tag{22}$$

Similarly, the power allocation factor of a user which transmits during ABS can also be obtained as Formula (21) where $IN_u = \sum\limits_{b'=2, b' \neq b}^{N_{\text{B}}} |h_{u,b'}|^2 P_{b'} + \sigma^2 B$. Due to the constraints in Formula (18),

$$\frac{\gamma_{\text{TH}} S_1 + \gamma_{\text{TH}} IN_1}{S_1 + \gamma_{\text{TH}} S_1} \leq \alpha \leq \frac{S_2 - \gamma_{\text{TH}} IN_2}{S_2}. \tag{23}$$

Since the signals are recovered at the receivers through SIC technology, the power allocation factor should not be too large or too small. Therefore, the power allocation factor is limited to the interval $[0.6, 0.9]$ in this paper and the optimal power allocation factor is expressed as:

$$\alpha^* = \min\left(\max\left(\frac{\gamma_{\text{TH}}S_1 + \gamma_{\text{TH}}IN_1}{S_1 + \gamma_{\text{TH}}S_1}, \alpha_0, 0.6\right), \frac{S_2 - \gamma_{\text{TH}}IN_2}{S_2}, 0.9\right). \tag{24}$$

3.5. Joint Optimization Scheme of Adaptive CRE and ABS

For the macrocell m, the traversal method to find the optimal solution of CRE and ABS will use the N_m^{PBS}-circulation to traverse all feasible solutions where N_m^{PBS} is the number of PBSs in the macrocell m. The complexity of the traversal method is extremely high. This paper uses the idea of game theory to change the N_m^{PBS}-circulation into N_m^{PBS} mutual independent circulation processes and finds the optimal solution by an iterative method.

Firstly, we initialize the ABS ratio allocated by the MBS in the macrocell m and then we assume that each PBS in the macrocell m is selfish and will take the best CRE bias value while calculating the CRE bias of PBS. The CRE biases of PBSs are calculated in order and will tend to be stable after a certain number of iterations. Then we will achieve the optimal CRE bias matrix under the current ABS ratio. By traversing all feasible solutions of the ABS ratio, the result will be obtained. The joint optimization algorithm of adaptive CRE and ABS is shown in Algorithm 2.

Algorithm 2 Joint Optimization Algorithm of Adaptive CRE and ABS

STEP1:	Initialize: the macrocell id $m = 1$, the number of macrocells N_{M}, the ABS ratio value $\boldsymbol{\xi} = [\xi_1, \xi_2, \ldots, \xi_{N_{\text{M}}}]$,the CRE bias value $\boldsymbol{\eta} = [\boldsymbol{\eta}_1, \boldsymbol{\eta}_2, \ldots, \boldsymbol{\eta}_{N_{\text{M}}}]$, $\boldsymbol{\eta}_m = \left[\eta_1, \eta_2, \ldots, \eta_{N_{\text{M}}^{\text{P}}}\right]$, where N_{M}^{P} represents the same number of PBSs in each macrocell, current iteration step $t = 1$, the maximum iteration step $T_{\max}$, the PBS id $p = 1$.

STEP2:	**while** $m \le N_{\text{M}}$ **do**
	$\xi_m = 1/8$.
	while $\xi_m < 1$ **do**
	$t = 1$.
	while $t \le T_{\max}$ **do**
	$p = 1$.
	while $p \le N_m^{\text{P}}$ **do**
	Traverse the feasible solutions of the CRE bias of the PBS p and calculate the objective function expressed in Formula (8).
	Update the solution ξ_m^*, $\boldsymbol{\eta}_m^*$ that maximizes the objective function.
	$p = p + 1$.
	end while
	$t = t + 1$.
	end while
	$\xi_m = \xi_m + 1/8$.
	end while
	$m = m + 1$.
	end while

STEP3:	Return optimal solution $\boldsymbol{\xi}^*$, $\boldsymbol{\eta}^*$.

It is assumed that the complexity of calculating Formula (8) is $O(N_{\text{U}})$ and N_{U} represents the number of users of the networks. Then the complexity of Algorithm 2 is $O\left(N_{\text{M}}N_{\text{ABS}}T_{\max}N_{\text{M}}^{\text{P}}N_{\text{CRE}}N_{\text{U}}\right)$ where the number of feasible solutions of the ABS ratio and CRE bias are denoted by N_{ABS} and N_{CRE}. Compared with the complexity of the traversal method $O\left(N_{\text{M}}N_{\text{ABS}}{N_{\text{CRE}}}^{N_{\text{M}}^{\text{P}}}N_{\text{U}}\right)$, this algorithm can effectively reduce the computational complexity, and the larger N_{CRE} is, the more obvious the complexity advantage of the algorithm in this paper.

4. Simulation Results

The specific simulation parameters are shown in Table 1. In the scenario, users are not evenly distributed. Part of the users near the PBS and the remains are randomly distributed in the macrocell. If not clearly stated, this paper sets 60 users in each macrocell. The path loss model and shadow fading are given in [2]. Moreover, the noise density of −174 dBm/Hz is shown in [8] while the statis power of the MBS and PBS are shown in [31].

Table 1. Parameters simulation.

Parameters	Values
Macrocell layout	500 m macro-layer with 3 macrocell
Picocell layout	2 picocell per macrocell
Number of users	60 per macrocell
User layout	20 users randomly distributed within 80 m range per picocell, the remaining users randomly distributed per macrocell
Transmit power	MBS: 46 dBm; PBS: 30 dBm
Bandwidth	20 MHz
Path loss	MBS to user : $128.1 + 37.6\ \log_{10}(R)$ dB in km PBS to user : $140.7 + 36.7\ \log_{10}(R)$ dB in km
Shadow fading	10 dB
Noise power	$-174 + 10\ \log_{10}(BW)$ dBm
Static power	MBS: 10 W; PBS: 0.1 W
Times of Monte Carlo simulation	100,000

The relation between the average throughput of edge users and the fairness index under the proposed user pairing scheme is shown in Figure 3a. Moreover, the pairing scheme adopts a fixed power allocation scheme and the joint optimization algorithm of adaptive CRE and ABS shown in this paper. As the power allocation factor increases, both the average throughput of edge users and the fairness index grow simultaneously. As the throughput of edge users becomes higher, the resource allocation is more balanced and the network fairness index is higher. Moreover, that can prove that the performance of edge users can reflect the network fairness to a certain extent. The average throughput of edge users and the fairness index under different user pairing schemes are shown in Figure 3b. The fixed power allocation factor is 0.9 because the proposed scheme achieves the best performance with this power allocation factor in Figure 3a. The RUP scheme is a random user pairing while the near-far user pairing (NFUP) scheme and uniform channel gain difference (UCGD) pairing scheme are shown in reference [32]. These schemes are selected for comparison because of their similar complexity. Compared with NFUP and UCGD, the average throughput of edge users of MBS in RUP is higher. Because the distribution of base stations in HetNets is complex, the traditional pairing scheme performed by channel gain is not suitable for HetNets. The users with good channel gain in MBS may suffer severe cross-tier interference from PBSs, resulting in poor user performance. The closer the fairness index is to 1, the better the fairness in the network. The fairness of RUP is greater than that of NFUP and UCGD and that means that the allocation of base station resources is unbalanced in NFUP and UCGD and we need a novel user pairing scheme for HetNets. The proposed pairing scheme combined with ABS technology in this paper can greatly improve the throughput performance of edge users and network fairness. This is because we set the condition that the throughput of the user does not drop as the transmission subframe is switched. The users will be dynamically switched from non-ABS to ABS according to the ABS ratio before pairing. Moreover, the users are paired by SINR instead of channel gain so that the resources of BS can be assigned preferably.

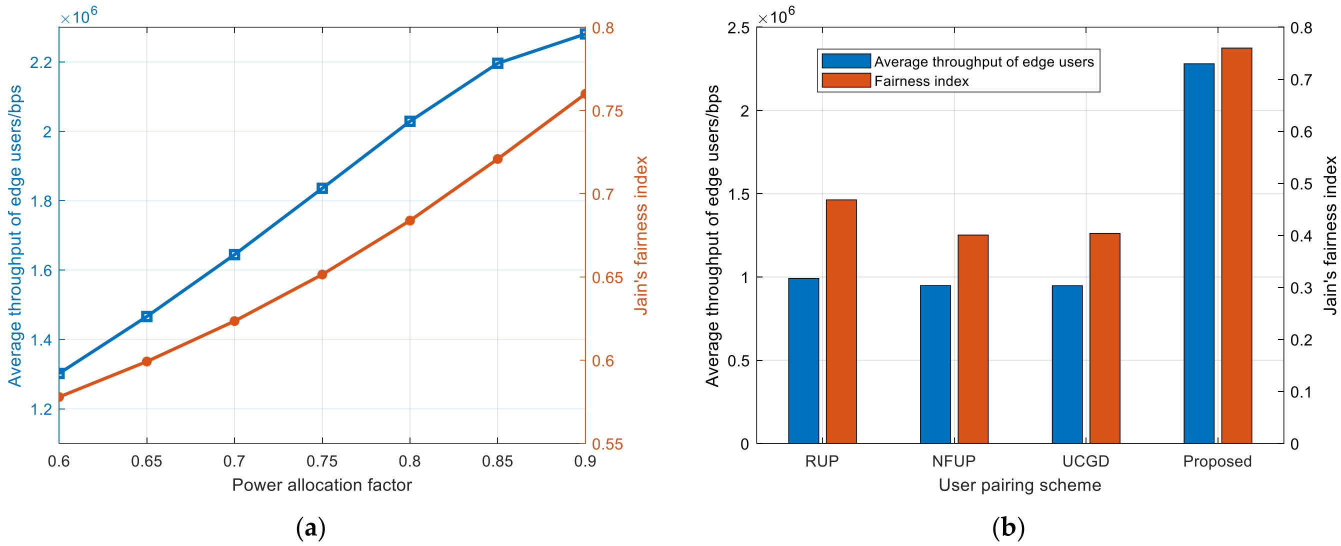
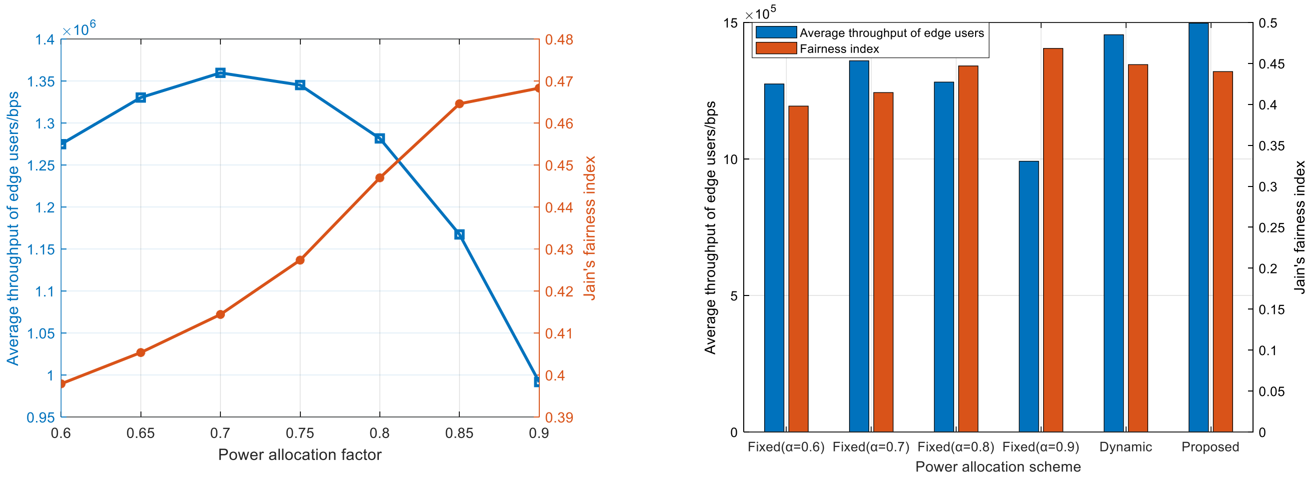


Figure 3. Throughput performances of edge users and fairness index: (**a**) under proposed user pairing scheme with different power allocation factors; (**b**) under different user pairing schemes ($\alpha = 0.9$).

The relation between the average throughput of edge users and the fairness index under the random user pairing scheme is shown in Figure 4a. Under the random user pairing scheme with fixed power allocation, the power allocation factor has an optimal value with the best performance in edge users because there is an optimal resource allocation strategy in the network. As the power allocation factor increases, the fairness index of the networks increases. Since the power allocation factor is higher, the performance difference between strong users and weak users is smaller and the fairness is getting better with the decline of edge user performance. Although the network fairness is better, the network performance is worse which is not desirable. Moreover, the comparison results of power allocation schemes are shown in Figure 4b. Each power allocation scheme adopts the random user pairing scheme and the joint optimization algorithm of adaptive CRE and ABS shown in this paper. The simulation only compares the independent power allocation schemes to illustrate the effectiveness of the proposed power allocation scheme. The optimization scheme of most papers is a scheme of integrating power allocation with other aspects of optimization. It is difficult to simulate the effectiveness of the power allocation scheme alone. Therefore, it is not considered in this paper. Due to the difference in users in different pairs, a fixed power allocation scheme cannot meet the requirement of each pair of users at the same time and the dynamic power allocation can operate efficiently [14]. The proposed power allocation scheme dynamically allocates the power allocation factor of users in the same pair to ensure that the throughput difference of users in the same pair is minimized. That can balance the performance of network users and have better performance in network edge users with similar network fairness than the dynamic power allocation scheme in reference [14]. Compared with the fixed power allocation scheme, the proposed power allocation scheme can improve network fairness while ensuring the performance of edge users. The proposed power allocation is used to equalize the performance of users in the same pair. Due to the different transmit power levels in macrocells and picocells, the balanced results of user throughput in macrocells and picocells are different. The difference between balanced user throughput may be greater than that of unbalanced user throughput and the fairness index is slightly lower than the maximum fairness index of the fixed power allocation scheme.



(**a**) (**b**)

Figure 4. Throughput performances of edge users and fairness index: (**a**) under random user pairing scheme with different power allocation factor; (**b**) under different power allocation schemes.

Through the above analysis, both the user pairing scheme and power allocation scheme have an impact on the performance of edge users and network fairness. Moreover, the user pairing scheme has a greater impact. Simulation results under different schemes are shown in Table 2. The schemes of Table 2 contain the scheme in Figures 3b and 4b with the best performance of edge users. Moreover, the proposed user pairing scheme can achieve better performance in edge users and improve network fairness. The proposed power allocation scheme can effectively enhance the throughput of edge users as the network fairness index decreases slightly. Therefore, the proposed strategy in this paper can obtain better performance in edge users with a high level of network fairness than other schemes. Moreover, there are two numerical results for the joint optimization algorithm of adaptive CRE and ABS with the proposed method and the traversal method; the proposed method has less complexity than the traversal method. Due to the randomness of random pairing, the proposed adaptive optimization algorithm cannot efficiently obtain the optimal solution; however, the error of the proposed pairing scheme between the two methods is approximately 0.20% in terms of throughput performance.

Table 2. Simulation results under different schemes.

Scheme	Average Throughput of Network Edge Users (Mbps) (Proposed/Traversal)	Fairness Index (Proposed/Traversal)
Fixed power allocation + Proposed user pairing	2.2808/2.2855	0.7600/0.7868
Proposed power allocation + random user pairing	1.4974/1.5931	0.4400/0.6984
Proposed power allocation + Proposed user pairing	2.5196/2.5244	0.7614/0.7657

The simulation results under different network user scales in NOMA HetNets with the proposed strategy are shown in Table 3. The average throughput of edge users decreases with the scale of users increase. Because the more users there are, the fewer resources are allocated. Moreover, the proposed strategy can efficiently balance resources and keep network fairness at a high level. As the user scale increases, the throughput of single users decreases, but the total throughput of the network does not change significantly, so the energy efficiency basically remains unchanged. The simulation results under different network models are shown in Table 4. The network models as a comparison can be seen in [15]. The network models with NOMA have better performance in edge users and energy efficiency than network models with OMA. The proposed strategy can effectively enhance the performance of edge users and energy efficiency as the fairness index declined in OMA HetNets. Moreover, the NOMA HetNets with the proposed strategy can improve the performance of edge users, fairness and energy efficiency by the proposed interference coordination strategy in the paper.

Table 3. Simulation results under different network user scales.

The Number of Users in Each Macrocell	Average Throughput of Edge Users (Mbps)	Fairness Index	Energy Efficiency (Mb/J)
15	10.02	0.75	5.38
30	5.14	0.75	5.24
45	3.45	0.80	5.30
60	2.52	0.76	5.31
75	2.02	0.78	5.31
90	1.69	0.81	5.33

Table 4. Simulation results under different network models.

Network Models	Average Throughput of Edge Users (Mbps)	Fairness Index	Energy Efficiency (Mb/J)
OMA HetNets	0.60	0.50	3.81
OMA HetNets with proposed strategy	1.24	0.34	4.27
NOMA HetNets	1.02	0.50	4.28
NOMA HetNets with proposed strategy	2.52	0.76	5.31

5. Conclusions

In this paper, a time-domain interference coordination optimization strategy of NOMA HetNets for network user fairness is proposed. In the strategy, CRE and ABS technology are applied to interference coordination. Novel user pairing schemes based on ABS ratio and dynamic power allocation schemes are proposed. Moreover, the idea of game theory is used to reduce the computational complexity of joint optimization algorithm of adaptive CRE and ABS. Simulation and numerical results present that the proposed user pairing scheme and power allocation scheme have better performance in edge users with a high level of network fairness than other schemes of similar complexity. Moreover, the proposed interference coordination optimization strategy can effectively improve the throughput performance of edge users and fairness in the network model of NOMA HetNets.

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