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Efficient non-orthogonal multiple access with simultaneous user association and resource allocation

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Abstract. In this study, the concepts of simultaneous user association and resource allocation in non-orthogonal multiple access systems have been investigated. Subscribers are randomly distributed in them. In the paper, a novel cooperative energy harvesting model is introduced so that user equipment near to the base stations acts as relay for further subscribers. In order to consider the local limitations of alternative energy resources, it was assumed that alternative energy would be shared among the base stations by means of the dynamic grid network. In this architecture, non-orthogonal resource allocation and user association frameworks should be reconfigured because conventional schemes use orthogonal multiple access. Hence, this paper suggests a novel approach to joint optimum cooperative power allocation and user association techniques to achieve a maximum degree of energy efficiency for the whole system in which the quality of experience parameters are assumed to be bounded during multi-cell multicast sessions. The model was also modified to develop joint multi-layered resource control and user association that can distinguish the service pattern in cooperative energy heterogeneous systems with non-orthogonal multiple access to obtain more resource optimality than in the current approaches. The effectiveness of the suggested approach is confirmed by numerical results. Also, the results reveal that non-orthogonal multiple access can provide greater energy efficiency than the conventional orthogonal multiple access approaches such as e.g. the MAX-SINR scheme.

Key words: power efficiency, quality of experience, non-orthogonal multiple access, resource allocation, user selection, green wireless networks.

1. Introduction

One of the key targets for next-generation mobile networks is the improvement of energy efficiency as compared with current networks. Because of the increase in fast speed services [1], such as the Internet of Things and mobile data services, a large percentage of user equipment will be connected to next-generation cellular networks [2]. This will cause an unprecedented increase in general energy consumption by adding a huge number of subscribers. The latest studies on global energy consumption patterns indicate that one-tenth of all energy consumed is dedicated to data transfer and telecommunications [3]. Furthermore, global environmental issues, such as uncontrolled use of carbon fuel, cause significant concerns, and greener approaches must be considered in order to increase network performance based on efficient energy consumption patterns.

Among the novel approaches, the use of renewable energy as an alternative resource appears to be a viable approach. The current grid energy consumption of next-generation cellular networks can be significantly reduced by permitting each evolved node B (eNB) to change the energy consumption model and draw energy from alternative energy sources (e.g. wind or solar power). Furthermore, promoting energy-based cooperation among eNBs using smart grid infrastructure can increase the efficiency of an alternative energy distribution scheme [4].

1.1. Related works and motivation. Although the use of new energy resources appears to be an alternative to the current grid energy in next-generation mobile networks, some critical issues exist such as how to become used to new energies and resource management circumstances [6]. With the ability to harvest alternative (renewal) energy in the network, base stations will pick up variable levels of the alternative resource because of the fluctuating nature of such alternative power resources. But when the alternative energy dedicated to the eNB fails to be consistent with the traffic load, the harvested energy will become insufficient to meet user requirements. Under these conditions, some subscribers should be handed over to more distant eNBs, having sufficient energy, although service will then be affected by signal-level degradation. Also, some eNBs may have more accessible energy, based on weather and environmental conditions, in which the unusable power will be wasted. Meanwhile, integrating eNBs with massive power storage systems will impose additional costs on the network [7] and the deployment of storage devices cannot resolve energy fluctuations in the architecture of the distributed cell layer in multicarrier mobile networks. So, power-sharing and energy cooperation among the eNBs through power management strategies may be the only viable solution [8].

Power-sharing in a point-to-multipoint transmission scenario has previously been investigated in [5, 8, 9]. Ulukus

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studied one-way resource sharing and power transfer through a multi-direction Gaussian channel using multiple access techniques [9]. This was extended to a cooperative energy model based on two-way energy transfer pattern by Hussein Al Haj [5]. The valuable cooperative energy approach by Liu [10] was implemented based on CDMA/OFDMA multiple access techniques and on relay-based multiple access channels in the networks. In [11], Deng presented a novel resource cooperation method in cognitive radio wireless networks in which the performance of the scheme was evaluated from the spectrum efficiency and energy management perspectives.

The potential of renewable energy management and alternative power cooperation in next-generation cellular networks is now being taken into consideration and a significant number of researchers have formulated energy cooperation frameworks and the related optimization problems. One valuable work that combines energy efficiency and spectrum assignment has been presented by Xu [7], who introduced an energy-aware spectrum sharing scheme among neighbor cellular networks. Different authors also tried to solve the convex optimization problem to minimize the cost of energy distribution and spectrum sharing. In [12], Mohajer formulated a new power control scheme in a distributed eNB layer in which energy demand of eNBs and the picked-up energy is assumed to be deterministic. The aim of Huang in [13] was to minimize the cost of an energy exchange framework through a categorized-prices smart grid. The target of Zhang [14] was to maximize the total transmission rate by solving convex optimization problems in which eNBs are distributed in a coordinated cluster. Bingyu [15] formulated the goal functions to achieve the optimum value for the mean cost of the resources exchanged by eNBs. The Lyapunov dynamic optimization model was applied here instead of statistical analysis of the transmission channels.

Not only were the most reviewed studies static and based on a solid foundation, but also previous studies had only considered energy cooperation and power-sharing in new-generation mobile networks with orthogonal multiple access (OMA) technology and had ignored non-orthogonal multiple access (NOMA) for energy cooperation in multicarrier mobile networks.

Multiple access techniques in cellular mobile networks enable the system to share accessible resources such as bandwidth, power and time between subscribers within the framework of a distinct resource control algorithm. Multiple access techniques can be divided in terms of orthogonality into twofold OMA and NOMA schemes. In the OMA approach, power, time and frequency resources are assigned orthogonally in order to decrease inter/intra-cell interference. Resource allocation in NOMA is based on exploiting domains such as code and power, and the most effective specification of this approach is related to saving bandwidth and time resources [17]. One major difference between NOMA and OMA is spectral efficiency; thus, in NOMA, eNBs are permitted to serve multiple subscribers at a same time at a distinct frequency. The main topic of the current research is the improvement of network performance with NOMA technology with particular focus on resource management. In a scenario with multiple users and one serving base station, the system approaches the ideal level of downlink energy efficiency by achieving optimum value for goal function [18]. This work has been extended to increase network capacity using MIMO to multiply the downlink throughput [17]. This research has shown that the quality of experience (QoE) in NOMA systems is one of the most critical indices. Tabassum [19] suggested an adaptive downlink/uplink resource allocation framework and dynamic power control formulated for dual stream wireless networks in which the average downlink throughput and outage timing constraints were bounded. Wu [20] has proposed a novel approach in distributed resource control by solving iterative convex optimization problems with the goal of minimizing transmission power and providing acceptable rate fairness.

In addition to investigating schemes for optimized resource allocation, other studies [21–23] have focused on joint resource control and power allocation in non-orthogonal multiple access systems as a new concept reaching beyond current resource management. Di [21] applied a combination of subcarrier allocation and resource assignment to achieve the optimum point of overall network consuming energy. Jiang [22] solved the resource/subchannel assignment problem to minimize the total dedicated power. Lei [23] introduced a sub-optimum framework as a centralized multicarrier scheme for maximizing total capacity in non-orthogonal multiple access systems under a single eNB scenario.

Despite the valuable studies conducted on the architecture and configuration of non-orthogonal systems, cooperative resource management in this type of networks has not been discussed to date. User association is relevant for user grouping and specification of base stations to each user group for transmission management [24], and the number of users assigned to each base station has a significant effect on system performance and energy-efficiency in non-orthogonal multiple access systems. Resource control techniques also play a significant role in intra/inter cell interference coordination and using resource control techniques enhances the quality of experience for users located at the cell edges. Subscriber satisfaction increases accordingly [17].

1.2. Challenges and contributions. Although some studies have examined resource management and power control in conventional orthogonal multiple access systems, cooperative resource management in non-orthogonal multiple access systems remains an open problem, particularly from the user association perspective. Most current non-orthogonal systems are based on single site scenarios [18–23] and the effect of inter-cell and external interference on practical multicarrier mobile networks has not been discussed, while inter-cell interference has a major effect on network functionality. Scenarios such as those for Prestegard [25] have used joint resource allocation and user association in current OMA mobile networks and single site non-orthogonal multiple access networks [26].

Previous schemes have not considered radio frequency characteristics of multi-cell non-orthogonal networks and thus do not seem to be effective. Also, current studies on user association-based alternative energy harvesting scenarios [27] merely consider the design of user associations in orthogonal multiple access systems without power-sharing and resource cooperation. It can be concluded that joint user association and resource control in an energy-cooperative multi-cell network with non-orthogonal multiple access has not been thoroughly addressed so far. While considering these concepts, the present article addresses energy-cooperative resource allocation and user association problems in two-layered heterogeneous mobile networks with non-orthogonal multiple access. The chief contributions of this article include:

- Presentation of downlink resource management in a two-layered non-orthogonal heterogeneous network in which a high-power macro eNB is the serving base station for distributed small cells and pico cells. In this scenario, each eNB will be powered by both the usual grid energy and alternative energy (solar energy or wind power) and cells can share the renewable energy among themselves. This novel approach goes beyond the conventional resource allocation and power control concepts to optimize the user association, downlink transmission power, energy exchanged among eNBs and consumption of the grid resource with the goal of achieving energy efficiency for the overall network in addition to satisfying user quality of experience constraints.
- The first stage of the proposed scheme is user association with the fixed transmission power. A decentralized framework is suggested to achieve the most efficient user association solution by solving convex optimization problems along with Lagrangian iterative analysis where network functionality will improve in comparison with conventional optimization schemes and genetic-based user associations with uniform population density.
- Hybrid cooperative power control and a user association algorithm are both suggested to further maximize energy efficiency. The functionality of the proposed algorithms is compared with previous schemes for samples without alternative energy management and cooperative energy schemes, such as fractional transmission power allocation (FTPA).
- The simulation and numerical results prove that the proposed approach increases energy efficiency in comparison with current schemes. The proposed resource management and power control framework comprehensively considers the effect of inter/intra cell interference in contrast to current schemes. Furthermore, by applying the proposed algorithm, more diversity and eNB densification gain will be achievable.

The remaining part of the paper is organized as follows: Section 2 introduces the system model and problem formulation. Section 3 presents the suggested resource management framework with fixed and dynamic downlink transmission power. Section 4 presents the cooperative energy resource allocation scheme with fixed user association and the proposed combined adaptive resource control along with user association approaches. The conclusions and recommendations for future study are presented in Section 5.

2. Network model and problem formulation

The network structure and problem formulation for resource allocation, energy harvesting, cooperative resource management and user association in heterogeneous non-orthogonal multiple access networks is modeled in this section.

2.1. Downlink transmission model. Figure 1 shows the two-layered cooperative energy heterogeneous network with

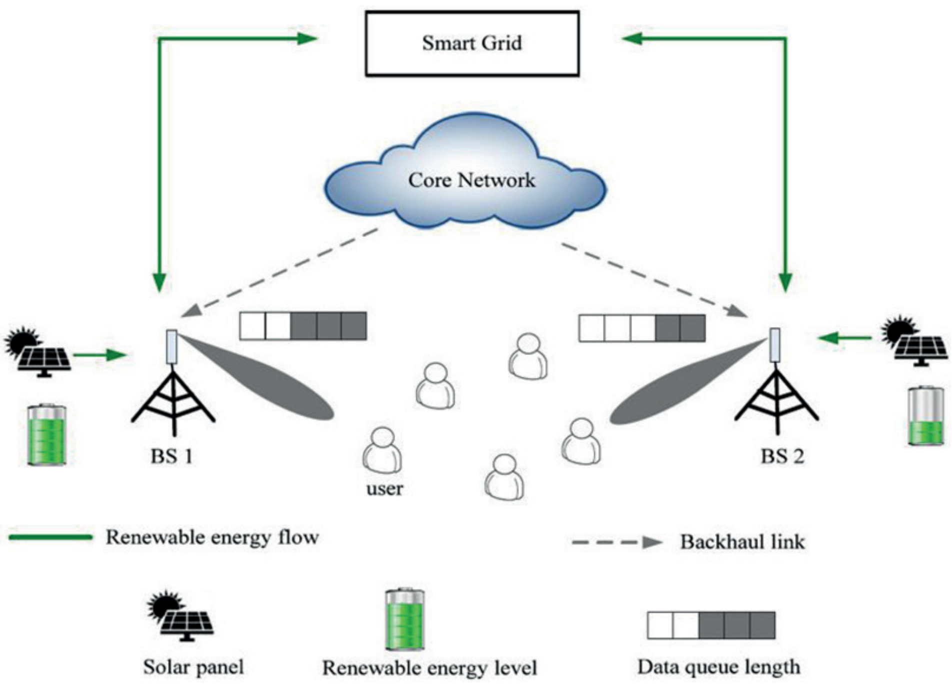

Fig. 1. Structure of cooperative energy multi-layered heterogeneous system powered via current grid and alternative resources

a macro base station (MBS) and distributed pico base stations (PBSs). The number of macro base stations is denoted by M and the frequency bandwidth shared by all base stations is assumed to be the same. In this scenario the "eNB", as a component of LTE radio access network in the new-generation mobile networks, is called "base station" in order to simplify understanding the scenario. Each base station is powered by both the usual grid and alternative energy resources (solar energy or wind power), and the base stations can share the renewable energy among themselves through a smart grid.

According to Fig. 2, in this model the source is denoted by the base station and two separate subscribers, Ai and Bi, which are distributed randomly.

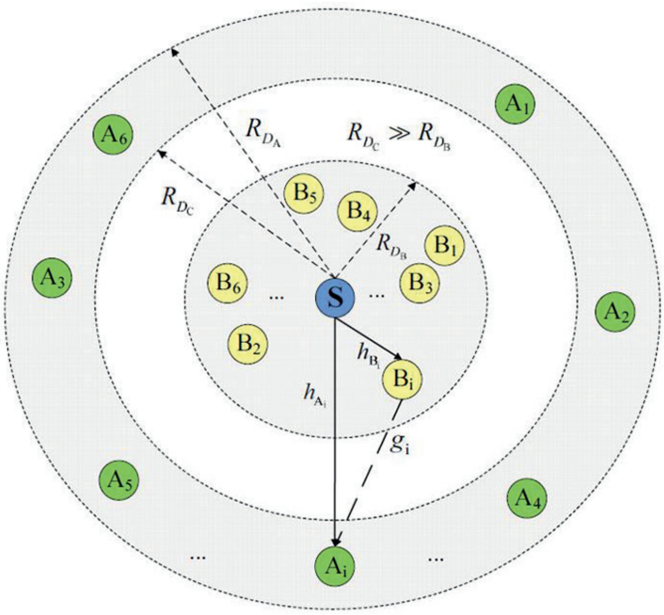

Fig. 2. Green heterogeneous network modelling: user association and resource allocation

2.2. Direct transmission. The two above-mentioned user groups demonstrated by Ai and Bi are associated under the non-orthogonal multiple access procedure. In the first stage, the base station submits two messages $pi1xi1 + pi2xi2$ towards these two indicated users, in which Pi1 and Pi2 denote resource allocation factors and xi1 and xi2 denote the messages of subscribers Ai and Bi accordingly. In this regard, user Ai can observe equation (1):

$$yA_i,\, 1 = \sqrt{P_S} \sum_{k\in\{1,2\}} p_{ik}\, X_{ik} \frac{h_{A_i}}{\sqrt{1+d_{A_i}^{\alpha}}} + n_{A_i},\, 1, \tag{1}$$

In which P_S denotes transmission power of each base station and h_{A_i} is relevant to the effect of Rayleigh fading from the base station to user Ai. n_{A_i}, 1 demonstrates a noise level which is Gaussian white noise. In order to receive message Xi, we can define the level of SINR at user Ai as:

$$\gamma_{S,A_i}^{X_i 1} = \frac{\rho |h_{A_i}|^2 |P_{i1}|^2}{\rho |P_{i2}|^2 |h_{A_i}|^2 + 1 + d_{A_i}^{\alpha}}, \tag{2}$$

where the level of signal to noise (SNR) is defined as $\rho = \frac{p_S}{\delta^2}$.

$$yB_i,\, 1 = \sqrt{P_S} \sum_{k\in\{1,2\}} P_{ik}\, X_{ik} \frac{\sqrt{1-\beta_i}\, h_{B_i}}{\sqrt{1+d_{B_i}^{\alpha}}} + n_{B_i},\, 1 \tag{3}$$

Hence, subscriber Bi senses the signal to noise and interference level equal to (4) for detection of message Xi1.

$$\gamma_{s,B_i}^{x_{i_1}} = \frac{\rho |h_{B_i}|^2 |P_{i1}|^2 (1-\beta_i)}{\rho |h_{B_i}|^2 |P_{i2}|^2 (1-\beta_i) + 1 + d_{B_i}^{\alpha}} \tag{4}$$

And in the same way, subscriber Bi will face an SNR level equal to equation (5) for receiving Xi2.

$$\gamma_{s,B_i}^{x_{i_2}} = \frac{\rho |h_{B_i}|^2 |P_{i2}|^2 (1-\beta_i)}{1 + d_{B_i}^{\alpha}} \tag{5}$$

In this formulation, β_i indicates the energy harvested coefficient while supported throughput via channel for decoding message Xi1 from the base station is calculable as equation (6):

$$R_{x_{i1}} = \frac{1}{2} \log\left(1 + \frac{\rho |h_{B_i}|^2 |P_{i1}|^2 (1-\beta_i)}{\rho |h_{B_i}|^2 |p_{i2}|^2 (1-\beta_i) + 1 + d_{B_i}^{\alpha}}\right). \tag{6}$$

We can assume that the power harvested coefficient is as in equation (7).

$$\beta_i = max\left\{0{,}1 - \frac{T_1\left(1 + d_{B_i}^{\alpha}\right)}{\rho\left(|P_{i1}|^2 - T_1 |P_{i2}|^2\right)|h_{B_i}|^2}\right\}. \tag{7}$$

Following from equation (3), we can conclude that the value of the harvested energy is:

$$E_{B_i} = \frac{T\eta P_S \beta_i |h_{B_i}|^2}{2\left(1 + d_{B_i}^{\alpha}\right)}. \tag{8}$$

In which, T indicates overall time of transmission stage and sharing energy time. Also, η demonstrates the resource harvested multiplier. So, the transmission power of user Bi will be indicated as below:

$$P_T = \frac{\eta P_S \beta_i |h_{B_i}|^2}{\left(1 + d_{B_i}^{\alpha}\right)}. \tag{9}$$

2.3. Cooperated transmission. At this stage, subscriber Bi sends x_{i1} to subscriber Ai by applying harvested energy in a direct transmission scenario. In it, subscriber Ai can find:

$$y_{A_{i,2}} = \frac{\sqrt{P_t} X_{i1} g_i}{\sqrt{1 + d_{C_i}^{\alpha}}} + n_{A_i}, 2. \tag{10}$$

In this formulation, g_i exhibits Rayleigh fading from subscriber Bi towards Ai with nobi and Ai. Also, ise variance δ^2. $d_{C_i} = \sqrt{d_{A_i}^2 + d_{B_i}^2 - 2d_{A_i} d_{B_i} \cos(\theta_i)}$ denotes the distance between subscriber θ_i and demonstrates the angle between AiSBi.

According to equations (9) and (10), the signal to noise level on the Ai side will be achievable as:

$$\gamma_{A_i B_i}^{x_{i_1}} = \frac{P_t |g_i|^2}{(1 + d_{C_i}^{\alpha})\sigma^2} = \frac{\eta \rho \beta_i |h_{B_i}|^2 |g_i|^2}{(1 + d_{C_i}^{\alpha})(1 + d_{B_i}^{\alpha})}. \tag{11}$$

Accordingly, we can calculate the received signal to noise interference for user Ai as equation (12):

$$\begin{aligned} \gamma_{A_i, MRC}^{x_{i_1}} = & \frac{\rho |h_{A_i}|^2 |P_{i1}|^2}{\rho |h_{A_i}|^2 |P_{i2}|^2 + 1 + d_{A_i}^{\alpha}} + \\ & + \frac{\eta \rho \beta_i |h_{B_i}|^2 |g_i|^2}{(1 + d_{B_i}^{\alpha})(1 + d_{C_i}^{\alpha})}. \end{aligned} \tag{12}$$

3. NOMA-based user association

In this part, we evaluate the functionality and efficiency of 3 user association approaches based on formal assessment.

3.1. RNRF user association. The approach of random near user and random far user is a relevant selection category for a close subscriber Bi and a far subscriber Ai, as located in relevance to the base station. In this approach, each subscriber can have access to the resource according to the non-orthogonal multiple access pattern, in which we can define the benefit of this method as not requiring the knowledge about the status of channels or channel state information (CSI).

In this approach, the outage probability can be defined as equation (13).

$$\begin{aligned} P_{B_i} = & Pr\left(\frac{\rho |h_{B_i}|^2 |P_{i1}|^2}{\rho |h_{B_i}|^2 |p_{i2}|^2 + 1 + d_{B_i}^{\alpha}} < T_1 \right) + \\ = & Pr\left(\frac{\rho |h_{B_i}|^2 |P_{i1}|^2}{\rho |h_{B_i}|^2 |P_{i2}|^2 + 1 + d_{B_i}^{\alpha}} > T_1, \gamma_{S_i B_i}^{x_{i_2}} < T_2 \right) \end{aligned} \tag{13}$$

In which the maximum level of detection of Xi2 by subscriber Bi is equal to $\tau_2 = 2^{2R_2} - 1$. Also, the outage probability of close subscribers in this approach can be expressed as:

$$P_{B_i} \approx \frac{1}{2} \sum_{n=1}^{N} \omega_N \sqrt{1 - \phi_n^2} \left(1 - e^{-c_n \varepsilon_{A_i}}\right)(\phi_n + 1). \tag{14}$$

In which, $\varepsilon_{A_i} = \frac{T_1}{\rho(|P_{i1}|^2 - |P_{i2}|^2 T_1)}$ and $\varepsilon_{B_i} = \frac{T_2}{\rho |P_{i2}|^2}$. And the outage probability formulation is achievable by means of considering equations (4, 5, 13) in equation (15).

$$P_{B_i} = Pr\left(Y_i < \varepsilon_{A_i}\right) + Pr\left(Y_i > \varepsilon_{A_i}, \varepsilon_{A_i} < \varepsilon_{B_i}\right). \tag{15}$$

This formulation shows that we face outage probability equal to 1 if $\varepsilon_{A_i} < \varepsilon_{B_i}$. With this in mind, we can define the outage density function of W_{Ai} and W_{Bi} as equation (16) and (17), respectively.

$$f w_{B_i}(\omega_{B_i}) = \frac{\measuredangle \Phi_B}{\mu_{R_{D_B}}} = \frac{1}{\pi R_{D_B}^2} \tag{16}$$

$$f w_{A_i}(\omega_{A_i}) = \frac{\measuredangle \Phi_A}{\mu_{R_{D_A}}} = \frac{1}{\pi \left(R_{D_A}^2 - R_{D_C}^2\right)} \tag{17}$$

On the other hand, in condition: $\varepsilon_{A_i} > \varepsilon_{B_i}$, the CDF function of Y_i is obtainable as:

$$\begin{aligned} F_{Y_i}(\varepsilon) = & \int_{D_B} \left(1 - e^{-(1 + d_{B_i}^{\alpha})^{\varepsilon}}\right) f w_{B_i}(\omega_{B_i}) d\omega_{B_i} = \\ = & \frac{2}{R_{D_B}^2} \int_0^{R_{D_B}} \left(1 - e^{-(1 + r^{\alpha})^{\varepsilon}}\right) r dr. \end{aligned} \tag{18}$$

We can use the Gauss-Chebyshev approaches in order to obtain solution of equation (18):

$$F_{Y_i}(\varepsilon) \approx \frac{1}{2} \sum_{n=1}^{N} \omega_N \sqrt{1 - \phi_n^2} \left(1 - e^{-c_n \varepsilon}\right)(\phi_n + 1). \tag{19}$$

In this regard, the outage probability of B_i is achievable as:

$$P_{B_i}|_{\alpha=2} = 1 - \frac{e^{-\varepsilon_{A_i}}}{R_{D_B \varepsilon A_i}^2} + \frac{e^{-\left(1 + R_{D_B}^2\right)\epsilon_{A_i}}}{R_{D_B}^2 \varepsilon_{A_i}}. \tag{20}$$

According to equation (20), the solution is achieved as:

$$F_{Y_i}(\varepsilon)|_{\alpha=2} = 1 - \frac{e^{-\varepsilon}}{R_{D_B \varepsilon}^2} + \frac{e^{-\left(1 + R_{D_B}^2\right)\epsilon}}{R_{D_B}^2 \varepsilon}. \tag{21}$$

According to this, outage probability will be calculated as:

$$\begin{aligned} P_{A_i} = & Pr\left(\gamma_{A_i, MRC}^{x_{i_1}} < T_1, \gamma_{S, B_i}^{x_{i_1}}|_{\beta_i = 0} > T_1\right) + \\ & + Pr\left(\gamma_{S, A_i}^{x_{i_1}} < T_1, \gamma_{S, B_i}^{x_{i_1}}|_{\beta_i = 0} < T_1\right). \end{aligned} \tag{22}$$

In which, subject to condition RDC $\gg$ RDB, subscriber Ai will face outage probability of:

$$P_{A_i} \approx \varsigma_1 \sum_{n=1}^{N} (\phi_n + 1)\sqrt{1 - \phi_n{}^{2c_n}} \sum_{k=1}^{K} \sqrt{1 - \psi_{k^{s_k}}^2} \left(1 + s_k^{\alpha}\right)^2$$
$$\times \sum_{m=1}^{M} \sqrt{1 - \varphi_{m^e}^2} - \left(1 + s_k^{\alpha}\right)^{t_m} Xt_m \left(\frac{Xt_m\left(1 + s_k^{\alpha}\right)}{\eta\rho} c_n + 2_{c_0}\right) \quad (23)$$
$$+ a_1 \sum_{n=1}^{N} \sqrt{1 - \phi_{n^2}}\, c_n(\phi_n + 1) \sum_{k=1}^{K} \sqrt{1 - \psi_{k^2}} \left(1 + s_k^{\alpha}\right) s_{k,}.$$

We have applied parameters M and K in order to control the problem from an accuracy-complexity perspective.

$$\varsigma_1 = -\frac{\varepsilon_{A_i R_{D_{B_i}}} \omega_N \omega_K \omega_M}{8\left(R_{DA_i} + R_{DC_i}\right)\eta p},\ \chi t_m = T_1 - \frac{\rho t_m |P_{i1}|^2}{\rho t_m |P_{i1}|^2 + 1},$$
$$t_m = \frac{\varepsilon A_i}{2}(\varphi_m + 1),\ \omega_m = \frac{\pi}{M},\ \varphi_m = \cos\left(\frac{2m-1}{2M}\pi\right),$$
$$S_k = \frac{R_{DA} - R_{DC}}{2}(\psi_k + 1) + R_{DC},\ \omega_k = \frac{\pi}{K},$$
$$\psi_k = \cos\left(\frac{2k-1}{2K}\pi\right),\ C_0 = -\frac{\varphi(1)}{2} - \frac{\varphi(2)}{2},$$
$$\text{and } a_1 = \frac{\omega_K \omega_N \varepsilon_{A_i}^2}{2\left(R_{DA} + R_{DC}\right)}.$$

Also, for simplicity of the problem we can define the outage probability of subscriber Ai as:

$$P_{A_i}|_{\alpha=2} \approx \varsigma_2 \sum_{k=1}^{K} \sqrt{1 - \psi_k^2}\, s_k \left(1 + s_k^2\right)^2 \sum_{m=1}^{M} \sqrt{1 - \varphi_m^2} +$$
$$+ \left(1 - \frac{e^{-\left(1 + R_{D_C}^2\right)\varepsilon_{A_i}}}{\varepsilon_{A_i}\left(R_{D_B}^2 - R_{D_C}^2\right)} + \frac{e^{-\left(1 + R_{D_A}^2\right)\varepsilon_{A_i}}}{\varepsilon_{A_i}\left(R_{D_A}^2 - R_{D_C}^2\right)}\right) \quad (24)$$
$$\times \left(1 - \frac{e^{-\varepsilon_{A_i}}}{R_{D_B}^2 \varepsilon_{A_i}} + \frac{e^{-\left(1 + R_{D_B}^2\right)\varepsilon_{A_i}}}{R_{D_B}^2 \varepsilon_{A_i}}\right).$$

In which, $\varsigma_2 = -\frac{\omega_K \omega_N \varepsilon_{A_i}^2\left(R_{D_B}^2 \Delta + 2\right)}{8\left(R_{DA} + R_{DC}\right)\eta p}$ and

$$b_0 = -\frac{\left(1 + R_{D_B}^2\right)^2 \mathrm{In}\left(1 + R_{D_B}^2\right)}{2R_{D_B}^2} + \left(R_{D_B}^2 + 2\right)\left(C_0 - \frac{1}{4}\right).$$

High signal to noise approximations can be considered as:

$$F_{Y_i}(\varepsilon) \approx \frac{1}{2} \sum_{n=1}^{N} \omega_N \sqrt{1 - \phi_{n^2}}\, c_n \varepsilon_{A_i}(\phi_n + 1). \quad (25)$$

And gain of diversity is calculated as:

$$d = -\lim_{\rho \to \infty} \frac{\log P(\rho)}{\log \rho}. \quad (26)$$

Note that for far subscribers, formulation (27) is achieved according to equations (23) and (26).

$$d = -\lim_{\rho \to \infty} \frac{\log\left(-\frac{1}{\rho^2}\log\frac{1}{\rho}\right)}{\log \rho} =$$
$$= -\lim_{\rho \to \infty} \frac{\log\log\rho - \log\rho^2}{\log\rho} = 2 \quad (27)$$

According to the outage probability model, we can conclude that the total throughput of this approach is achievable as:

$$R_{TRNRF} = \left(1 - P_{A_i}\right)R_1 + \left(1 - P_{B_i}\right)R_2. \quad (28)$$

It should be noted that parameters P_{A_i} and P_{B_i} are obtained via equations (23) and (14), respectively.

3.2. NNNF user association. In the approach of nearest near user and nearest far user, the base station elects a subscriber inside ring D_B with lowest distance to the base station as a close user demonstrated with Bi. In this approach, near nodes can have the role of relays for far subscribers. The approach of nearest near user and nearest far user can dedicate more energy to nearer subscribers as total harvested energy.

In this approach, the outage probability approximation is calculated as in equation (29):

$$P_{B_i} \approx b_1 \sum_{n=1}^{N} \sqrt{1 - \phi_{n^2}} \left(1 - e^{-\left(1 + c_{n*}^{\alpha}\right)^{\varepsilon} A_i}\right) c_{n*} e^{-\pi \lambda_{\Phi_B} C^2 n*} \quad (29)$$

in which if $\varepsilon_{A_i} \geq \varepsilon_{B_i}$, otherwise $P_{B_{i*}} = 1$,

where $c_{n*} = \frac{R_{DB}}{2}(\phi_n + 1)$, $b_1 = \frac{\xi_B \omega_N R_{DB}}{2}$, and $\xi_B = \frac{2\pi\lambda_{\Phi_B}}{1 - e^{-\pi\lambda_{\Phi_B} R_{D_B}^2}}$.

Also, same as (15), the outage probability of subscriber Bi is shown as:

$$P_{B_{i*}} = \Pr\left(Y_{i*} < \varepsilon_{A_i} | N_B \geq 1\right) = \mathrm{F}_{Y_{i*}}\left(\varepsilon_{A_i}\right) \quad (30)$$

where $Y_{i*} = \frac{|h_{B_i}|^2}{1 + d_{B_{i*}}^{\alpha}}$ denotes the distance between the nearest subscriber and the base station. In this regard, the CDF function of Y_{i*} is as follows:

$$\mathrm{F}_{Y_{i*}}(\varepsilon) = \int_O^{R_{D_B}} \left(1 - e^{-\left(1 + r_B^{\alpha}\right)^{\varepsilon}}\right) f d_{B_{i*}}(r_B) dr_B$$
$$\Pr\left\{d_{B_{i*}} > r | N_B \geq 1\right\} \quad (31)$$

$$\Pr\left\{d_{B_{i*}} > r | N_B \geq 1\right\} =$$
$$= \frac{\mathrm{pr}\left\{d_{B_{i*}} > r\right\} - \Pr\left\{d_{B_{i*}} > r, N_B = 0\right\}}{\mathrm{P}_r\left\{N_B \geq 1\right\}} = \quad (32)$$
$$= \frac{e^{-\pi\lambda_\Phi B^{r^2}} - e^{-\pi\lambda_\Phi B^{R_{D_B}^2}}}{1 - e^{-\pi\lambda_\Phi B^{R_{D_B}^2}}}.$$

The relevant PDF function of subscriber Bi is shown by:

$$fd_{B_{i^*}}(r_B) = \xi_B r_B e^{-\pi\lambda_{\Phi_B} r_B^2}. \tag{33}$$

By considering equations (33) and (31), formulation (34) is achievable.

$$F_{Y_{i^*}}(\varepsilon) = \xi_B \int_O^{R_{D_B}} \left(1 - e^{-(1+r_B^\alpha)^\varepsilon}\right) r_B e^{-\pi\lambda_{\Phi_B} r_B^2} dr_B \tag{34}$$

In which by using the Gauss-Chebyshev method, we obtain:

$$\begin{aligned} \mathrm{F}_{Y_{i^*}}(\varepsilon) \approx \frac{\xi_B \omega_N R_{D_B}}{2} \sum_{n=1}^{N} \sqrt{1-\phi_{n^2}} \times \\ \times \left(1 - e^{-(1+c_{n*}^\alpha)^\varepsilon}\right) c_{n*} e^{-\pi\lambda_{\Phi_B} C^2 n*}. \end{aligned} \tag{35}$$

Under special condition $\alpha = 2$, the outage probability of subscriber Bi is demonstrated as the following formulation:

$$\begin{aligned} P_{B_i}|_{\alpha=2} = \frac{\xi_B \left(e^{-R_{D_B}^2 (\pi\lambda_{\Phi_B} + \varepsilon_{A_i}) - \varepsilon_{A_i}} - e^{-\varepsilon_{A_i}}\right)}{2(\pi\lambda_{\Phi_B} + \varepsilon_{A_i})} - \\ - \frac{\xi_B \left(e^{-\pi\lambda_{\Phi_B} R_{D_{B-1}}^2}\right)}{2\pi\lambda_{\Phi_B}}. \end{aligned} \tag{36}$$

Also, the outage probability of A_{i^*} is exhibited as equation (37).

$$\begin{aligned} P_{A_{i^*}} \approx \varsigma^* \sum_{n=1}^{N} \sqrt{1-\Phi_{n^2}} \left(1 + c_{n^*}^\alpha\right) c_{n*} e^{-\pi\lambda_{\Phi_B} C^2 n*} \times \\ \times \sum_{k=1}^{K} \sqrt{1-\psi_k^2} \left(1 + s_k^\alpha\right)^2 s_{k e^{-\pi\lambda_{\Phi_A}}} \left(s_k^2 - R_{D_C}^2\right) \times \\ \times \sum_{m=1}^{M} \sqrt{1-\varphi_m^2}\, e^{-(1+s_k^\alpha)t_m} \times \\ \times Xt_m \left(\ln \frac{Xt_m (1+s_k^\alpha)(1+c_{n*}^\alpha)}{\eta\rho} + 2c_0\right) + \\ + b_2 b_3 \sum_{k=1}^{K} \sqrt{1-\psi_k^2} \left(1 + s_k^\alpha\right) s_{k e^{-\pi\lambda_{\Phi_A}}} s_k^2 \times \\ \times \sum_{n=1}^{N} \left(\sqrt{1-\Phi_{n^2}} \left(1 + c_{n^*}^\alpha\right) c_{n*} e^{-\pi\lambda_{\Phi_B} C^2 n*}\right), \end{aligned} \tag{37}$$

where $\varsigma^* = -\frac{\xi_B \xi_A \omega_N \omega_K \omega_M \varepsilon_{A_i} R_{D_B} (R_{D_A} + R_{D_C})}{8\eta\rho}$, and

$b_2 = \frac{\xi_A e^{\pi\lambda_{\Phi_A} R_{D_C}^2} \omega_K \varepsilon_{A_i}}{R_{D_A} + R_{D_C}}$, and $b_3 = \frac{\xi_B \omega_N R_{D_B} \varepsilon_{A_i}}{2}$.

Under special condition $\alpha = 2$, the outage probability of subscriber A_{i^*} is demonstrated as the following formulation:

$$\begin{aligned} P_{A_{i^*}}|_{\alpha=2} \approx \varsigma^* \sum_{n=1}^{N} \sqrt{1-\Phi_{n^2}} \left(1 + c_{n^*}^\alpha\right) c_{n*} e^{-\pi\lambda_{\Phi_B} C^2 n*} \times \\ \times \sum_{k=1}^{K} \sqrt{1-\psi_k^2} \left(1 + s_k^\alpha\right)^2 s_{k e^{-\pi\lambda_{\Phi_A}}} \left(s_k^2 - R_{D_C}^2\right) \times \\ \times \sum_{m=1}^{M} \sqrt{1-\varphi_m^2} \left(e^{-(1+s_k^\alpha)t_m} \times \right. \\ \left. \times Xt_m \left(\ln \frac{Xt_m (1+s_k^2)(1+c_{n*}^2)}{\eta\rho} + 2c_0\right)\right) + \\ + \frac{\xi_A e^{\pi\lambda_{\Phi_A} R_{D_C}^2}}{2} \left(\frac{e^{-\varepsilon_{A_i}}}{\pi\lambda_{\Phi_A} + \varepsilon_{A_i}} \left(e^{-R_{D_A}^2}(\pi\lambda_{\Phi_A} + \varepsilon_{A_i}) - \right.\right. \\ \left.\left. - e^{-R_{D_C}^2}(\pi\lambda_{\Phi_A} + \varepsilon_{A_i})\right) - \frac{\left(e^{-\pi\lambda_{\Phi_A} R_{D_A}^2 - \varepsilon_{A_i}} - e^{-\pi\lambda_{\Phi_A} R_{D_C}^2}\right)}{\pi\lambda_{\Phi_A}}\right) \times \\ \times \frac{\xi_B}{2} \left(\frac{e^{-R_{D_B}^2 (\pi\lambda_{\Phi_B} + \varepsilon_{A_i}) - \varepsilon_{A_i}} - e^{-\varepsilon_{A_i}}}{\pi\lambda_{\Phi_B} + \varepsilon_{A_i}} - \frac{e^{-\pi\lambda_{\Phi_A} R_{D_B}^2} - 1}{\pi\lambda_{\Phi_B}}\right) \end{aligned} \tag{38}$$

$$\begin{aligned} \mathrm{F}_{X_{i^*}}(\varepsilon)|_{\alpha=2} = -\frac{\xi_A \left(e^{\pi\lambda_{\Phi_A}(R_{D_B}^2 - R_{D_A}^2)} - 1\right)}{2\pi\lambda_A} + \\ + \frac{\xi_A e^{\pi\lambda_{\Phi_A} R_{D_C}^2} e^{-\varepsilon}}{2(\pi\lambda_A + \varepsilon)} \left(e^{-R_{D_A}^2(\pi\lambda_{\Phi_A} + \varepsilon)} - e^{-R_{D_c}^2(\pi\lambda_{\Phi_A} + \varepsilon)}\right). \end{aligned} \tag{39}$$

When $\varepsilon \to 0$, a high signal to noise ratio of (29) with $1 - e^{-x} \approx x$ is calculated as:

$$\mathrm{P}_{B_{i^*}} \approx b_1 \varepsilon_{A_i} \sum_{n=1}^{N} \left(\sqrt{1-\Phi_{n^2}} \left(1 + c_{n^*}^\alpha\right) c_{n^*} e^{-\pi\lambda_{\Phi} B^{C_{n*}^2}}\right). \tag{40}$$

According to the problem formulation, the total throughput level of this approach is achievable by the following formulation:

$$R_{TNNNF} = \left(1 - P_{A_{i^*}}\right) R_1 + \left(1 - P_{B_{i^*}}\right) R_2. \tag{41}$$

It should be noted that parameters P_{A_i} and P_{B_i} are obtaned via equations (37) and (29), respectively.

3.3. NNFF user association. The next approach is the nearest near user and farthest far user one, in which first, the ring D_B is considered for selection of the subscriber nearest to base station as a near non-orthogonal multiple access user. Also, the far user is selected inside ring D_A so that its distance from the base station is maximum.

Under condition of $R_{D_C} \gg R_{D_B}$ the outage probability of $A_{i'}$ can be expressed as:

$$
\begin{aligned}
P_{A_{i'}} \approx\ & \varsigma^{*} \sum_{n=1}^{N} \sqrt{1-\phi_{n^2}}\,\left(1+c_{n*}^{\alpha}\right) c_{n*}\, e^{-\pi\lambda_{\Phi} B^{C_{n*}^{2}}} \times \\
& \times \sum_{k=1}^{K} \sqrt{1-\psi_k^2}\,\left(1+s_k^{\alpha}\right)^2 s_k\, e^{-\pi\lambda_{\Phi_A}\left(R_{D_A}^2+s_k^2\right)} \times \\
& \times \sum_{m=1}^{M} \sqrt{1-\varphi_m^2}\; e^{-\left(1+s_k^{\alpha}\right)t_m} \times \\
& \times Xt_m\left(\mathrm{In}\,\frac{Xt_m\left(1+s_k^{\alpha}\right)\left(1+c_{n*}^{\alpha}\right)}{\eta\rho}+2c_0\right)+ \\
& + b_3 b_4 \sum_{k=1}^{K} \sqrt{1-\psi_{k^2}}\,\left(1+s_k^{\alpha}\right) s_{k^{e^{\pi\lambda_{\Phi_A}}}}\, s_k^2
\end{aligned}
\tag{42}
$$

where $b_4 = \dfrac{\xi A\, e^{-\pi\lambda_{\Phi_B} R_{D_A}^2}\, \omega_K\, \varepsilon_{A_i}}{R_{D_A}+R_{D_C}}$.

$$
\begin{aligned}
P_{A_{i'}}\big|_{\alpha=2} \approx\ & \varsigma^{*} \sum_{n=1}^{N} \sqrt{1-\phi_{n^2}}\,\left(1+c_{n*}^{2}\right) c_{n*} e^{-\pi\lambda_{\Phi} B^{C_{n*}^{2}}} \times \\
& \times \sum_{k=1}^{K} \sqrt{1-\psi_k^2}\,\left(1+c_{n*}^{2}\right)^2 s_k\, e^{-\pi\lambda_{\Phi_A}\left(R_{D_A}^2+s_k^2\right)} \times \\
& \times \sum_{m=1}^{M} \sqrt{1-\varphi_m^2}\,\left(e^{-\left(1+s_k^{2}\right)t_m} \times\right. \\
& \left.\times Xt_m\left(\mathrm{In}\,\frac{Xt_m\left(1+s_k^{2}\right)\left(1+c_{n*}^{2}\right)}{\eta\rho}+2c_0\right)\right)+ \\
& + \frac{\xi A\, e^{-\pi\lambda_{\Phi_A} R_{D_A}^2}}{2}\left(\frac{e^{\pi\lambda_{\Phi_A} R_{D_A}^2}-e^{\pi\lambda_{\Phi_A} R_{D_C}^2}}{\pi\lambda_{\Phi_A}}-\frac{e^{-\varepsilon_{A_i}}}{\pi\lambda_{\Phi_A}-\varepsilon_{A_i}}\times\right. \\
& \left.\times\left(e^{R_{D_A}^2}\left(\pi\lambda_{\Phi_A}+\varepsilon_{A_i}\right)-e^{R_{D_C}^2}\left(\pi\lambda_{\Phi_A}+\varepsilon_{A_i}\right)\right)\right)\times \\
& \times \frac{\xi_B}{2}\left(\frac{\left(e^{-R_{D_B}^2\left(\pi\lambda_{\Phi_B}+\varepsilon_{A_i}\right)-\varepsilon_{A_i}}-e^{-\varepsilon_{A_i}}\right)}{\pi\lambda_{\Phi_B}+\varepsilon_{A_i}}-\frac{\left(e^{-\pi\lambda_{\Phi_B} R_{D_B}^2}-1\right)}{\pi\lambda_{\Phi_B}}\right).
\end{aligned}
\tag{43}
$$

The total system throughput based on this approach is achievable as formulation (44):

$$
R_{TNNFF} = \left(1-P_{A_{i'}}\right)R_1+\left(1-P_{B_{i'}}\right)R_2. \tag{44}
$$

It should be noted that parameters P_{A_i} and P_{B_i} are obtaned via equations (42) and (29), respectively.

4. Simulation results

An effective comparison has been made between our proposed approach and one of the famous gradient-based algorithms under the name of MAX-SINR through various resource allocation scenarios. For simplicity of analysis of the simulation, the proposed algorithms are assumed to be independent of the distribution of alternative energy. Time-slotted Rayleigh/Rician fading in a slight mobility environment is applied because user association is usually effected in a large-scale timing mode and slow fading can be neglected [27]. Furthermore, pico cells and user equipment are identically distributed in the coverage of each macro cell. Table 1 shows the key simulation parameters.

Table 1
Key simulation parameters

Parameter	Value
BS layout	Hexagonally arranged cell sites
UE layout	Uniformly located in area with 3 active UEs per BS cell
Inter site distance	200 m
Bandwidth (B)	1 GHz
Carrier frequency of mmWave small cell	28 GHz
Thermal Noise power	-174 dBm/Hz $+ 10\log_{10}(B)$ + noise figure of 7 dB
Path loss of mmWave BS	$\alpha + 10\eta\log_{10}(m) + \xi$ $\xi \sim \mathcal{N}(0, \sigma^2)$, LOS: $\alpha = 61.4$, $\eta = 2$, $\sigma = 5.8$ dB, LOS: $\alpha = 72.0$, $\eta = 2.92$, $\sigma = 8.7$ dB [30]
Probability of Outage(O)-LOS-NLOS in mmWave small cell	O: $P_o(d) = \max\left\{0, 1 - e^{-\frac{d}{30}+5.2}\right\}$; LOS: $p_L(d) = \left(1 - P_o(d)\right)e^{-\frac{d}{67.1}}$; NLOS: $1 - P_o(d) - p_L(d)$ [30]
Maximum transmit power of BS	40 dBm
Log-normal shadowing fading	10 dB
Antenna gain of BS	18 dB
Antenna gain of UE	0 dB
Min harvested power	$a_j = [0, 20]$ dBm
Max harvested power	$b_j = [20, 40]$ dBm

4.1. Energy efficiency. This Section is related to evaluation of the suggested user association algorithm with a MAX-SINR scheme. This system does not use power control at the base stations. Using the power allocation formulation of non-orthogonal multiple access systems in Eq. (3), the total transmission power at each base station is $P_m = P_{max}^m$. A progressive resource allocation pattern is used for the sake of simplicity. For example, the transmission power of subscriber signaling is $P_{jm} = \dfrac{2j}{k_m(1+k_m)} P_m$, $j \in \{1, 2, 3, \ldots, k_m\}$, when k_m subscribers have been added to the independent power domain of sector m. The target is to analyze the performance of various user association approaches based on the coverage level and signal quality using an identical power allocation state. The functionality of the proposed

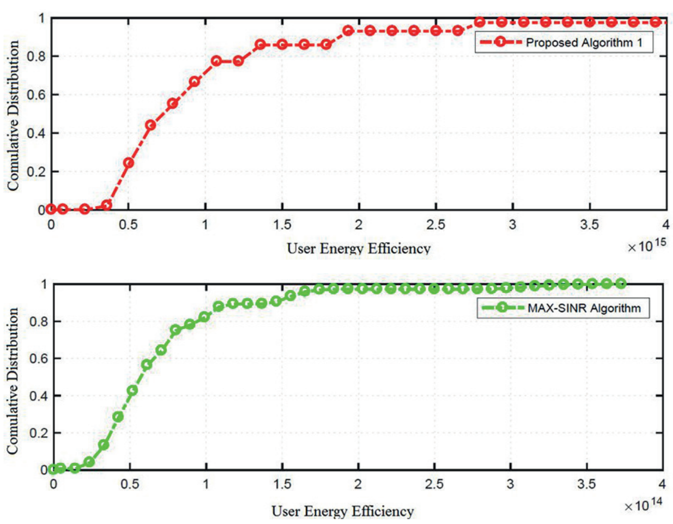

Fig. 3. Cumulative distribution function of user energy efficiency

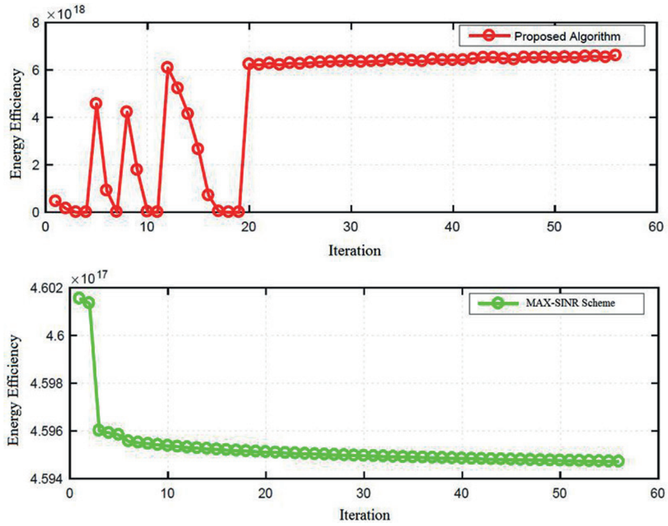

Fig. 5. Convergence behavior of energy efficiency

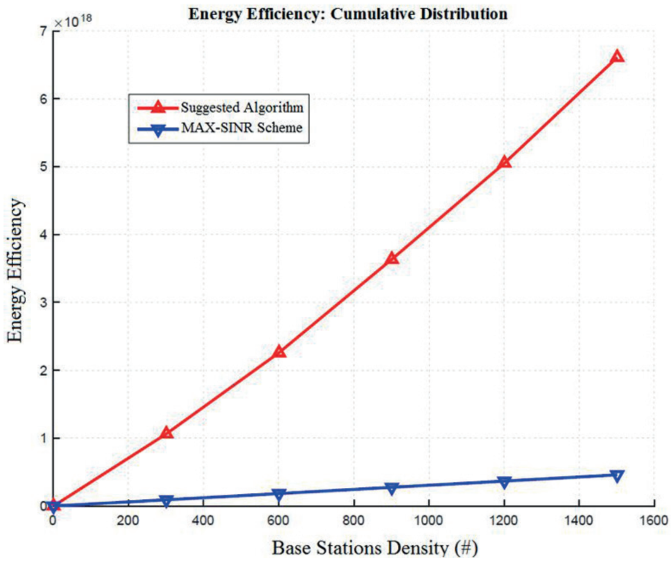

Fig. 4. Accumulation of energy efficiency

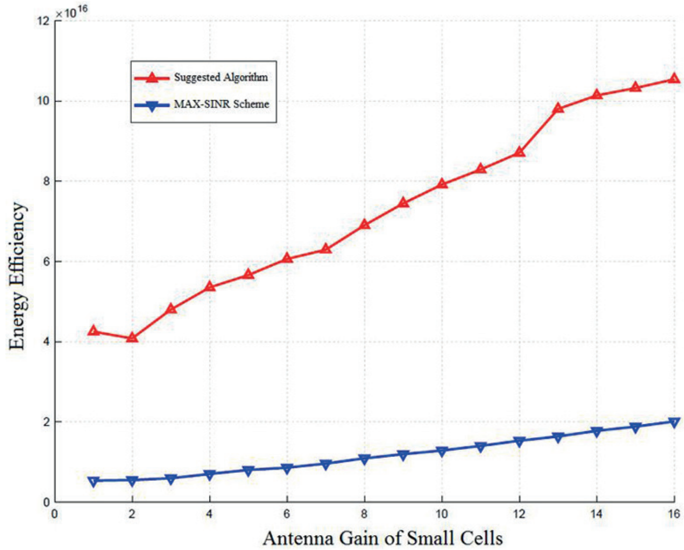

Fig. 6. Energy efficiency versus the mmWave small cell antenna gain

algorithm is compared with conventional user association using reference signal received power (RSRP).

4.2. Energy-efficient user association under power control. It was necessary to evaluate the power control enabled user association algorithm. The advantages of the combined resource control user association approach in cooperative power non-orthogonal multiple access HetNets were examined. The various resource assignments work with the reference signal received via power-based user association. Using orthogonal multiple access, the transmission power at each base station was determined to be $P_m = P_{max}^m$.

Figure 7 shows energy efficiency versus user density with M = 5 pico cells at $\beta_\varepsilon = 0.9$. The minimum required threshold for QoS was set at $\overline{\tau}_{min} = 0.5$ bits/s/Hz. The amount of energy accrued by the macro cells and pico cells was 39 and 34 dBm, respectively. The proposed hybrid resource control algorithm and user association showed better energy efficiency than in conventional models. There was a sharp increase in effectiveness when more user equipment was connected to the base stations. The proposed algorithm can achieve greater multi-user diversity gain. Non-orthogonal multiple access increases energy efficiency as compared with common orthogonal systems because of its increased spectral efficiency. Where there is fixed resource assignment, for non-orthogonal multiple access systems with common RSRP-based user associations, the degree of energy efficiency decreases as the number of subscribers increases. Also, as the number of users connected at the same time increases, the amount of power allocated to each data stream decreases for the specific signal level.

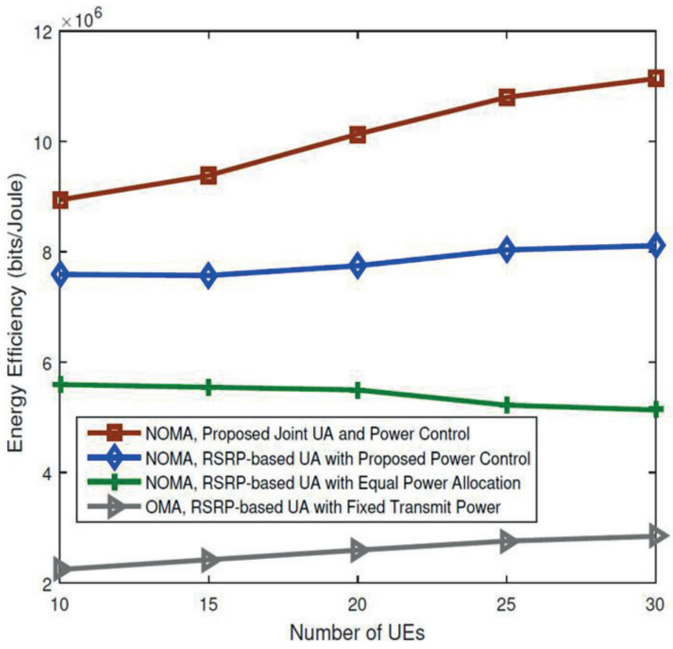

Fig. 7. Comparison of user association/resource allocation approaches from energy efficiency vs user equipment perspective

Figure 8 shows the energy efficiency versus density of the pico cells with 50 pieces of user equipment (N = 50) and $\beta_{\varepsilon} = 0.9$. The required QoS threshold was $\bar{\tau}_{min} = 0.1$ bits/s/Hz. The level of energy picked up by the macro and pico cells was 36 and 26 dBm, respectively. The proposed approach performed better than conventional schemes. The hybrid resource control and user association with non-orthogonal multiple access achieved significantly more energy efficiency with a greater number of pico cells because the proposed scheme can increase the base station densification gain. Non-orthogonal multiple access increases performance as compared with that of orthogonal systems. For the RSRP-based user association with NOMA and identical power allocation, the energy efficiency degraded as the density of pico cells increased because of inter-cell interference, which has a strong effect on NOMA transmission.

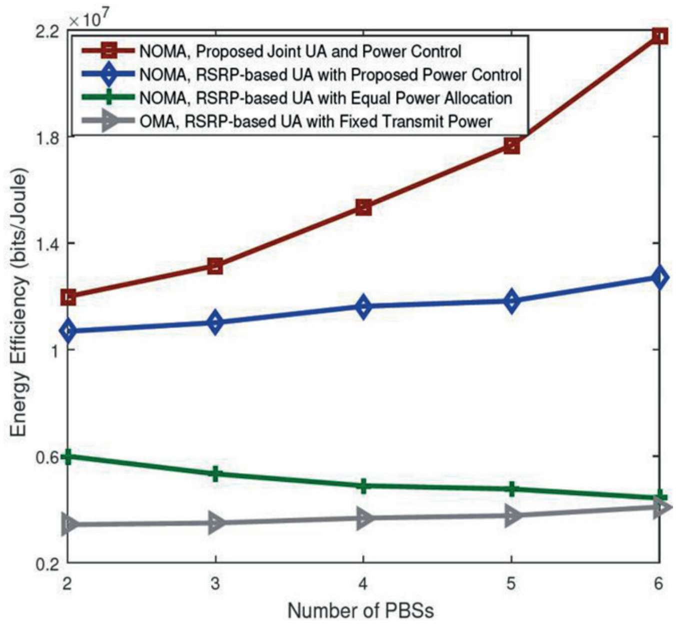

Fig. 8. Comparison of user association/resource allocation approaches from energy efficiency vs pico base stations perspective

5. Conclusions and future research directions

A novel approach in the field of intelligent resource allocation with resource cooperation among network entities has been proposed in this paper. In this research, the concepts of simultaneous user association and resource allocation in non-orthogonal multiple access systems have been investigated. subscribers are randomly distributed in those. In this paper, a novel cooperative energy harvesting model was introduced so that user equipment near to the base stations can act as relays for further subscribers. A joint resource control and user association algorithm was proposed that increases energy efficiency over that of conventional works, and the proposed resource control approach meets KKT optimality constraints. The numerical results confirmed the energy efficiency of the proposed approaches. Also, simulation revealed that the proposed approaches can optimally eliminate intra/inter cell interference and utilize multi-user diversity, in addition to a gain in base station densification. Non-orthogonal systems increased energy efficiency over that of orthogonal systems, which resulted from the superior spectral efficiency of non-orthogonal multiple access.

For further studies and to improve the proposed model, researchers can consider some limitations of the model. One of the most important indices which can be focused on is the outage probability model, for which we assume this index to be $\frac{\ln SNR}{SNR^2}$ although previous schemes have used $\frac{1}{SNR^2}$ instead. Application of the MIMO technology with non-orthogonal networks is also recommended for future crucial research to enhance energy efficiency when in MIMO-based non-orthogonal systems the inter-user equipment interference decreases effectiveness. So, finding ways of decreasing inter-user interference appears to be necessary. Finally, joint resource control and user association solutions in multi-cell non-orthogonal systems have not been deployed to date, especially in MIMO-based systems, and thus more research effort should be devoted to this subject.

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