An Optimal Joint User Association and Power Allocation Algorithm for Secrecy Information Transmission in Heterogeneous Integrated Networks

Mingxue Chen(✉), Yuanpeng Gao, Rong Chai, and Qianbin Chen

School of Communication and Information Engineering,
Chongqing University of Posts and Telecommunications, Chongqing, China
mingxuechen@outlook.com, gyp2342623@126.com, chairong@cqupt.edu.cn

Abstract. In recent years, radio access technologies have experienced rapid development and gradually achieved effective coordination and integration, resulting in heterogeneous networks (HetNets). User equipments (UEs) located in the overlapping area of various networks of HetNets are capable of selecting the base station (BS) of one network for association and conduct information interaction. In this paper, we study user association and power allocation problem for HetNets with eavesdroppers. To achieve secrecy data transmission in a secret and energy-efficient manner, the concept of joint secrecy energy efficiency of the network is introduced and is defined as the ratio of secrecy transmission rate and the power consumption of the BSs. An optimization problem is formulated which maximizes the joint secrecy energy efficiency under the constraints of maximum power of the BSs and the minimum data rate requirement of the UEs, and the optimal user association and transmit power strategy is obtained through applying iterative algorithm and Lagrange dual method. Numerical results demonstrate the efficiency of the proposed algorithm.

Keywords: HetNets · User association · Power allocation · Secrecy information transmission · Secrecy energy efficiency

1 Introduction

In recent years, radio access technologies have experienced rapid development and gradually achieved effective coordination and integration, resulting in HetNets [1], in which user equipments (UEs) located in the overlapping area of various networks are capable of selecting the base station (BS) of one network for association and information interaction. User association scheme design in HetNets is of particular importance for it may affect user quality of service (QoS) and network performance significantly.

Some research works have considered user association or cell association problem in HetNets. In [2], the authors addresses the cell association problem of a

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multi-tier HetNet and propose a unified distributed cell association and resource allocation algorithm to maximize the sum utility of long term rate with long term rate QoS constraints and maximize global outage probability with outage QoS constraints. The authors in [3] examine the impact of mobile backhaul networks on LTE-A HetNets, and propose a backhaul-aware user association algorithm to achieve network load balancing and the performance enhancement in terms of transmission delay and service block probability. In [4], user association problem in HetNets is studied and a distributed optimization method is proposed to maximize the utilization of the BSs.

References in [5,6] jointly consider user association and power allocation in HetNets. The authors in [5] study the joint BS association and power allocation problem for the downlink transmission in HetNets, and propose a two-stage algorithm to maximize the minimum data rate of the UEs. In [6], the authors consider the joint optimization of BS association and power allocation in a wireless downlink HetNet under the proportional fairness criterion and propose a utility function maximization based BS association and power allocation strategy.

It should be noted that compared to traditional cellular networks, the network architecture of HetNets becomes more open and diverse, which makes the information exchange more susceptible to eavesdropping, hence, the problem of secure transmission becomes extremely important in HetNets. In [7], the authors consider the network scenario in which eavesdroppers exist in HetNets and propose a joint resource allocation algorithm which jointly considers physical layer security, cross-tier interference and joint optimal allocation of power and subcarrier to maximize the achievable secrecy sum rate of the network. The authors in [8] investigate secure communications in a two-tier downlink HetNets, which comprises one macrocell and multiple femtocells with each cell having multiple users and an eavesdropper which attempts to wiretap the intended macrocell UEs. The authors consider an orthogonal spectrum allocation strategy to eliminate co-channel interference and propose the secrecy transmit beamforming scheme operating in the macrocell to maximize the secrecy rate of users.

In this paper, we study user association and power allocation problem for HetNets with eavesdroppers. To achieve data transmission in a secret and energy-efficient manner, the concept of joint secrecy energy efficiency of the network is introduced and is defined as the ratio of secrecy transmission rate and the power consumption of the BSs. An optimization problem is formulated which maximizes the joint secrecy energy efficiency under the constraints of maximum power of the BSs and the minimum data rate requirement of the UEs, and the optimal user association and transmit power strategy is obtained through applying iterative algorithm and Lagrange dual method.

The rest of the paper is organized as follows. Section 2 describes the system model considered in this paper. We jointly design user association and power allocation strategy for the heterogeneous integrated network described in Sect. 3. The solution of the optimization problem is discussed in Sect. 4. Simulation results are presented in Sect. 5. Finally, we conclude this paper in Sect. 6.

2 System Model

In this paper, we study the downlink transmission in a HetNet, which consisting of multiple overlapping access networks and a number of users, which may associate to one of the networks and conduct information interaction. We assume that each network is assigned a portion of spectrum and no spectrum sharing is allowed among networks and within each network, thus no transmission interference exists. Further assume that inside each network, there exists an eavesdropper which may eavesdrop the information of the UEs associated with the network.

We denote the number of networks and UEs by M and N, respectively. We assume each network only has one BS, for convenience, the BS of the ith network is referred to as BS_i, $1 \leq i \leq M$. We further assume that each UE can only associated with one BS and each BS can only serve one UE on given time-frequency resource block. Figure 1 shows the HetNet model we considered in this paper.

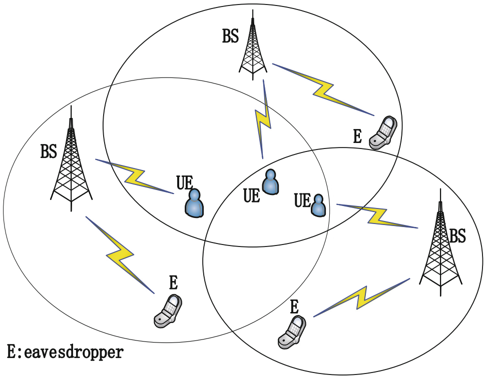

Fig. 1. System model

3 Secrecy Energy Efficiency Optimization Problem Formulation

In this section, the joint secrecy energy efficiency optimization is formulated.

$$\eta = \sum_{i=1}^{M} \sum_{j=1}^{N} x_{i,j} \eta_{i,j} \tag{1}$$

where $x_{i,j}$ denotes the association variable between BS_i and the jth UE(UE_j), and $\eta_{i,j}$ represents the secrecy energy efficiency of BS_i when associating with UE_j and can be expressed as:

$$\eta_{i,j} = \frac{R_{i,j}^{\mathrm{sec}}}{P_{i,j} + P^{\mathrm{cir}}} \tag{2}$$

where $R_{i,j}^{\mathrm{sec}}$ denotes the secrecy data transmission rate of the link between BS_i and UE_j, $P_{i,j}$ and P^{cir} denote the transmit power and the circuit consumption power of BS_i when transmitting to UE_j respectively. We assume that the circuit consumption power of the BSs is constant in this paper.

$R_{i,j}^{\mathrm{sec}}$ in (2) can be expressed as:

$$R_{i,j}^{\mathrm{sec}} = R_{i,j}^{\mathrm{u}} - R_{i,j}^{\mathrm{e}} \tag{3}$$

where $R_{i,j}^{\mathrm{u}}$ denotes the data rate of the link between BS_i and UE_j, $R_{i,j}^{\mathrm{e}}$ denotes the data rate of the eavesdropper when eavesdropping UE_j in the ith network. $R_{i,j}^{\mathrm{u}}$ in (3) can be expressed as:

$$R_{i,j}^{\mathrm{u}} = B_i \log\left(1 + \frac{P_{i,j} h_{i,j}}{\sigma^2}\right) \tag{4}$$

where B_i denotes the transmission bandwidth of BS_i, $h_{i,j}$ denotes the channel gain of the link between BS_i and UE_j, and σ^2 denotes the noise power, which is assumed to be a constant in this paper. $R_{i,j}^{\mathrm{e}}$ in (3) can be calculated as:

$$R_{i,j}^{\mathrm{e}} = B_i \log_2\left(1 + \frac{P_{i,j} h_i^{\mathrm{e}}}{\sigma^2}\right) \tag{5}$$

where h_i^{e} denotes the channel gain of the link between BS_i and the eavesdropper of the ith network

The problem of joint user association and power allocation algorithm for secrecy information transmission in HetNets can be formulated as following optimization problem:

$$\begin{aligned} \max_{x_{i,j}, P_{i,j}} \quad & \eta \\ \text{s.t.} \quad & \mathrm{C1}: \ P_{i,j} \geq 0, \\ & \mathrm{C2}: \ P_{i,j} \leq P_i^{\max}, \\ & \mathrm{C3}: \ \sum_{i=1}^{M} R_{i,j}^{\mathrm{sec}} \geq R_j^{\min}, \\ & \mathrm{C4}: \ x_{i,j} \in \{0,1\}, \\ & \mathrm{C5}: \ \sum_{j=1}^{N} x_{i,j} \leq 1, \\ & \mathrm{C6}: \ \sum_{i=1}^{M} x_{i,j} \leq 1. \end{aligned} \tag{6}$$

In (6), $P_i^{\max}$ denotes the maximum permissible power of BS_i, the constraint C2 represents that the transmit power of BS_i should be less than its maximum permissible power, $R_j^{\min}$ denotes the minimal secrecy data rate required from UE_j, apparently, the constraint C3 characterizes the data rate requirement of UE_j.

4 Solution of the Optimization Problem

The optimization problem formulated in (6) is a nonlinear mixed-integer optimization problem the solution which is difficult to obtain directly. Indeed, as it is assumed that each UE can only access one network and each network can only serve one UE for given resource block, and there is no cross interference between various networks, the power allocation for a particular UE-BS pair can be conducted independently to obtain the locally optimal transmit power, based on which user association can be performed. Hence, we can equivalently transform the original optimization problem into two subproblems, i.e., the subproblem of optimal power allocation, and the subproblem of user association. Through solving the two subproblems successively, the optimal joint power allocation and user association strategy can be obtained.

4.1 Optimal Power Allocation Subproblem

Assuming UE_j associates with the BS_i, i.e., $x_{i,j} = 1$, the optimal power allocation subproblem for BS_i can be formulated as follows:

$$\begin{aligned} \max_{P_{i,j}} \quad & \eta_{i,j} \\ \text{s.t.} \quad & \text{C1} - \text{C3 in (6)}. \end{aligned} \tag{7}$$

The optimization problem formulated in (7) is a nonconvex nonlinear fractional program, which can be transformed into a convex problem. Without loss of generality, we denote $q_{i,j}^*$ as the maximum secrecy energy efficiency of BS_i when associating to UE_j, which can be expressed as:

$$q_{i,j}^* = \frac{R_{i,j}^{\text{sec}}(P_{i,j}^*)}{P_{i,j}^* + P^{\text{cir}}}, \tag{8}$$

where $P_{i,j}^*$ denotes the optimal transmit power of BS_i when associating to UE_j. It can be proved that the maximum secrecy energy efficiency $q_{i,j}^*$ is achieved if and only if

$$\begin{aligned} & \max_{P_{i,j}} R_{i,j}^{\text{sec}}(P_{i,j}) - q_{i,j}^*(P_{i,j} + P_{cir}) \\ & = R_{i,j}^{(\text{sec},*)}(P_{i,j}^*) - q_{i,j}^* P_{i,j}^* = 0. \end{aligned} \tag{9}$$

Hence, the optimization problem expressed in (7) can be rewritten as:

$$\begin{aligned} & \max_{q_{i,j}, P_{i,j}} R_{i,j}^{\text{sec}}(P_{i,j}) - q_{i,j}(P_{i,j} + P_{cir}) \\ & \text{s.t.C1} - \text{C3 in (6)}. \end{aligned} \tag{10}$$

To obtain the optimal secrecy energy efficiency and transmit power strategy of (9), we apply an iterative algorithm. The proposed algorithm is summarized in Algorithm 1 and the convergence to the optimal secrecy energy efficiency can be guaranteed in [9] (Table 1).

Table 1. Algorithm 1. Solving secrecy energy efficiency maximization problem

1. Initialize the maximal iteration number $L_{\max}$ and the tolerate value ω
2. Set $q_{i,j}$=0 and the iterative index l=0
3. Repeat main loop
4. For a given $q_{i,j}$, solving power allocation subproblem to obtain the locally optimal power allocation strategy $P_{i,j}^{'}$
5. If $R_{i,j}^{\text{sec}}(P_{i,j}^{'}) - q_{i,j}(P_{i,j}^{'} + P^{\text{cir}}) \le \omega$ then
6. Convergence=true
7. Return $q_{i,j}^{*} = \frac{R_{i,j}^{\text{sec}}(P_{i,j}^{'})}{P_{i,j}^{'} + P^{\text{cir}}}$
8. else,set $q_{i,j} = \frac{R_{i,j}^{\text{sec}}(P_{i,j}{'})}{P_{i,j}{'} + P^{\text{cir}}}$ and let $l = l + 1$
9. end if
10. Until the algorithm is converged or $l = L_{\max}$

For a given $q_{i,j}$, the optimization problem formulated in (10) can be transformed into following problem:

$$\begin{aligned} &\max_{P_{i,j}} R_{i,j}^{\text{sec}} - q_{i,j}(P_{i,j} + P^{\text{cir}}) \\ &\text{s.t.C1} - \text{C3 in (6)} \end{aligned} \tag{11}$$

We apply Lagrange dual method to solve above optimization problem. The Lagrangian of the problem can be expressed as:

$$\begin{aligned} L(\alpha, \beta, P_{i,j}) = R_{i,j}^{\text{u}} - q_{i,j}(P_{i,j} + P^{\text{cir}}) \\ -\alpha(P_{i,j} - P_j^{\max}) - \beta(R_i^{\min} - R_{i,j}^{\text{sec}}), \end{aligned} \tag{12}$$

where α and β are Lagrange multipliers, the Lagrange dual problem of (12) can be formulated as follows:

$$\begin{aligned} &\min_{\alpha,\beta} \max_{P_{i,j}} L(\alpha, \beta, P_{i,j}) \\ &\text{s.t.} \quad \alpha \ge 0, \beta \ge 0 \end{aligned} \tag{13}$$

For a given set of Lagrange multipliers $\{\alpha, \beta\}$ using standard optimization techniques, the optimal power allocation policy $P_{i,j}$ can be obtained as:

$$P_{i,j} = \left[\frac{(h_{i,j} + h_i^e)\sigma^2 + ((h_{i,j} - h_i^e)\sigma^4 + 4h_{i,j}h_i^e t)^{1/2}}{2h_{i,j}h_i^e} \right]^{+} \tag{14}$$

where $t = \left[\frac{(1+\beta)B_j(h_{i,j}-h_i^e)\sigma^2}{(\alpha+q_{i,j})\ln 2}\right]^+$, $[z]^+ = \max\{0, z\}$.

The dual function is differentiable, the iterative algorithm can be used to solve the optimal Lagrange multipliers which leads to

$$\alpha(t+1) = [\alpha(t) - \varepsilon_1(P_i^{\max} - P_{i,j})]^+, \tag{15}$$

$$\beta(t+1) = [\beta(t) - \varepsilon_2(\sum_{i=1}^{M} R_{i,j}^{\text{sec}} - R_j^{\min})]^+. \tag{16}$$

where the iteration index $\varepsilon_i(i = 1, 2)$ is the positive step size.

4.2 User Association Subproblem

Through assuming $x_{i,j} = 1$, we can obtain the locally optimal power allocation strategy, denoted as $P_{i,j}^*$ and $q_{i,j}^*$. Substituting $P_{i,j}$ by $P_{i,j}^*$ in (1), we obtain:

$$\eta = \sum_{i=1}^{M}\sum_{j=1}^{N} x_{i,j} \frac{R_{i,j}^{\text{sec},*}}{(P_{i,j}^* + P^{\text{cir}})}, \tag{17}$$

where $R_{i,j}^* = B_i \log_2\left(1 + \frac{P_{i,j}^* h_{i,j}^2}{\sigma^2}\right)$. For given $P_{i,j}^*$, $\frac{R_{i,j}^{\text{sec},*}}{(P_{i,j}^*+P^{\text{cir}})}$ is a constant, therefore, the problem of maximizing (17) is equivalent to selecting the optimal $x_{i,j}$ subject to user association constraints, which can be expressed as the following optimal user association subproblem:

$$\begin{aligned} &\max_{x_{i,j}} \sum_{i=1}^{M}\sum_{j=1}^{N} x_{i,j} \frac{R_{i,j}^{\text{sec},*}}{(P_{i,j}^*+P^{\text{cir}})} \\ &\text{s.t.} \quad \text{C4} - \text{C6 in (6)} \end{aligned} \tag{18}$$

The optimization model formulated in (18) is a nonlinear integer optimization problem, which is in general very difficult to be solved. However, it can be observed that given the constraints on user association, the optimization problem can be described by a bipartite graph and the problem of optimal user association can be regarded as an optimal matching problem in the bipartite graph, which can then be solved based on the typical algorithm such as modified Kuhn-Munkres algorithm in [10].

A weighted bipartite graph G with bipartite division $G^0 = (V_1, V_2, E)$ is constructed, where the set of vertices V_1 represents the collection of the interrupted users, i.e., $\text{V}_1 = [\text{SU}_1, \text{SU}_2, \ldots, \text{SU}_M]$, SU_m represents the mth interrupted SU, $1 \leq m \leq M$, and the set of vertices V_2 represents the collection of subchannels, i.e., $V_2 = [\text{C}_1, \text{C}_2, \ldots, \text{C}_N]$, the weight of the edge, i.e., $E\{V_1, V_2\}$ is defined as:

The steps for solving the optimal user association subproblem based on the K-M algorithm can be described as follows.

1. Find an initial feasible vertex labeling and determine G_l^0 from G^0.
2. A distribution of H is selected in G_l^0.

3. If H is perfect, then the optimization problem is solved. Otherwise, the label having not being allocated by the distribution H is selected in G_l^0. Set $S = V_1$, and $\mathrm{T} = \Psi$, which denotes the empty set.
4. $N_{G_l^0}(S)$ denotes the collection of points which connect with S in G_l^0. If $N_{G_l^0}(S) \neq T$, go to step (2). Otherwise, $N_{G_l^0}(S) = T$. Find

$$\Delta = \min(l(u) + l(v) \geq w(u,v) | u \in S, v \in V_2 - T) \tag{19}$$

and replace existing labeling l with l' by

$$l'(u) = \begin{cases} l(u) - \Delta, & u \in S \\ l(u) + \Delta, & u \in T \\ l(u), & \text{others.} \end{cases}$$

The process continues until an equal subgraph consisting a complete match is obtained.

5 Simulation Results

In the simulation, we consider a HetNet scenario consisting of multiple overlapping access networks. Assuming the numbers of UEs and BSs are both chosen from 3 to 5, respectively. We assume that all users are randomly located in a rectangular region with the size being 100×100. The minimum rate requirements of UEs when associating to BS are 0.99 Mbps, 0.97 Mbps, 0.90 Mbps, 0.89 Mbps, 0.95 Mbps, 0.88 bps respectively, the noise power is -47 dBm, the bandwidth is 1 MHz. The simulation results are averaged over 1000 independent adaptation processes where each adaptation process involves different positions of UEs and eavesdroppers.

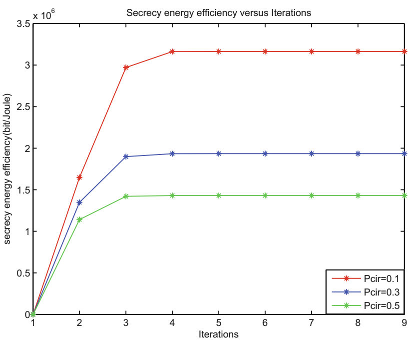

Fig. 2. Secure energy efficiency versus the number of iterations

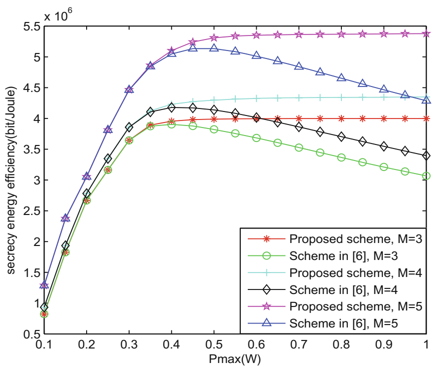

Fig. 3. The secrecy energy efficiency versus maximum transmit power (different number of BS)

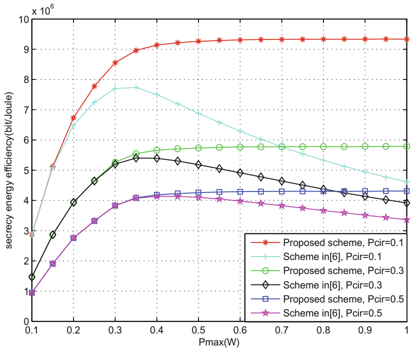

Fig. 4. Secrecy energy efficiency versus maximum transmit power (different circuit power)

Figure 2 shows the secrecy energy efficiency versus the number of iterations for different of circuit power. $P^{\max}$ is chosen as 0.8 W in plotting the figure. It can be observed that the iterative algorithm converges within a small number of iterations.

Figure 3 shows the secrecy energy efficiency versus the maximum transmit power for different numbers of BSs, and the results are obtained from the proposed scheme and the scheme proposed in [6]. P^{cir} is chosen as 0.5 W in plotting the figure. As the maximum transmit power increases, the proposed scheme performs better than the scheme proposed in [6]. This is because the scheme proposed in [6] failed to allocate the optimal power to the UEs, resulting in a undesired transmission performance. It also can be seen from the figure that for a small $P^{\max}$, the secrecy energy efficiency increases with the increasing of $P^{\max}$, indicating a larger power threshold is desired for achieving the maximum secrecy energy efficiency. However, as $P^{\max}$ reaches to a certain value, the secrecy energy efficiency becomes a fixed value for the transmit power being less than $P^{\max}$ has resulted in the optimal secrecy energy efficiency, which will no longer vary with $P^{\max}$.

The secrecy energy efficiency versus the maximum transmit power for different circuit power consumption is shown in Fig. 4. It can be seen from the figure that the total secrecy energy efficiency decreases with the increase of the circuit power consumption. Compared to the scheme proposed in [6], our proposed scheme offers larger secrecy energy efficiency.

6 Conclusion

In this paper, an optimal user association and power allocation scheme is proposed in HetNets. The factors, including channel characteristics and eavesdroppers are taken into account jointly in optimal UE association and allocating the transmit power of UEs, we formulate the problem of joint user association and resource allocation as an optimization problem with the objective function being the total secrecy energy efficiency of UEs in HetNets. The optimization problem which maximizes the secrecy energy efficiency for UEs is formulated and solved through iterative algorithm and Lagrange dual method. It is verified by simulation that the proposed algorithm achieves much better secrecy energy efficiency than the proposed scheme in [6] in HetNets.

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References

1. Jo, M., Maksymyuk, T., Batista, R.L., Maciel, T.F., de Almeida, A.L.F., Klymash, M.: A survey of converging solutions for heterogeneous mobile networks. IEEE Wirel. Commun. **21**(6), 54–62 (2014)
2. Boostanimehr, H., Bhargava, V.K.: Unified and distributed QoS-driven cell association algorithms in heterogeneous networks. IEEE Trans. Wireless Commun. **14**(3), 1650–1662 (2015)
3. Beyranvand, H., Lim, W., Maier, M., Verikoukis, C., Salehi, J.A.: Backhaul-aware user association in FiWi enhanced LTE-A heterogeneous networks. IEEE Trans. Wirel. Commun. **14**(6), 2992–3003 (2015)
4. Wang, L., Chen, W., Li, J.: Congestion aware dynamic user association in heterogeneous cellular network: a stochastic decision approach. In: 2014 IEEE International Conference on Communications (ICC), Sydney, NSW, pp. 2636–2640 (2014)
5. Sun, R., Hong, M., Luo, Z.Q.: Joint downlink base station association and power control for max-min fairness: computation and complexity. IEEE J. Select. Areas Commun. **33**(6), 1040–1054 (2015)
6. Shen, K., Yu, W.: Distributed pricing-based user association for downlink heterogeneous cellular networks. IEEE J. Select. Areas Commun. **32**(6), 1100–1113 (2014)
7. Shiqi, G., Chengwen, X., Zesong, F., Jingming, K.: Resource allocation for physical layer security in heterogeneous network with hidden eavesdropper. China Commun. **13**(3), 82–95 (2016)
8. Lv, T., Gao, H., Yang, S.: Secrecy transmit beamforming for heterogeneous networks. IEEE J. Select. Areas Commun. **33**(6), 1154–1170 (2015)
9. Khakurel, S., Musavian, L., Le-Ngoc, T.: Energy-efficient resource and power allocation for uplink multi-user OFDM systems. In: Proceedings of IEEE PIMRC 2012, Sydney, Australia, pp. 357–361, September 2012
10. Zhou, X., Yang, L., Yuan, D.: Bipartite matching based user grouping for grouped OFDM-IDMA. IEEE Trans. Wirel. Commun. **12**(10), 5248–5257 (2013)