LETTER

Sum Rate Maximization of Dense Small Cell Network with Load Balance and Power Transfer among SBSs

Xuefei PENG[†a)], ***Nonmember and*** **Xiao XUE**[††b)], ***Student Member***

SUMMARY This letter proposes a load balance and power transfer scheme among small cell base stations (SBSs) to maximize the sum rate of small cell network. In the proposed scheme, small cell users (SUEs) are firstly associated with their nearest SBSs, then the overloaded SBSs can be determined. Further, the methods, i.e., Case 1: SUEs of overloaded SBSs are offloaded to their neighbor underloaded SBSs or Case 2: SUEs of overloaded SBSs are served by their original associated SBSs through obtaining power from their nearby SBSs that can provide higher data rate is selected. Finally, numerical simulations demonstrate that the proposed scheme has better performance.

key words: *load balance, power transfer, data rate*

1. Introduction

Improving the quality of service for load, i.e., users through resource allocation method is a hot topic in wireless network [1]–[3]. Recently, some works have focused on the study of power allocation and load balance. To minimize the total power drawn by the base stations (BSs) from smart grid, the authors in [4], [5] analyzed the energy losses while guaranteeing safety and balancing out the power of the hybrid battery management system. Nevertheless, the application of this system in real wireless network is not discussed. The problem of load balance was considered in [6]–[11]. [6] discussed a central load balancing selection algorithm to save the resource. Different load balancing and interference management methods while considering cell association in cellular networks was studied in [7]. Authors in [8] considered cell zooming to achieve load balance of hyper cellular network. Moreover, sleeping strategy for BSs with light load was adopted to reduce power consumption and improve energy efficiency of the network. Authors in [9] proposed an optimal load balancing association method between remote radio heads and mobile devices to minimizes handovers. A novel energy-efficient ant-based routing algorithm was proposed in [10] to achieve load balancing and prolong the lifetime of wireless sensor network. Energy group buying with load sharing was proposed in [11] to reduce the energy costs of mobile network operators by utilizing their collaboration benefit. However, power transfer among small cell base stations (SBSs) is not considered in [6]–[11].

Different from existing literature, this letter adopts load balance and power transfer scheme among SBSs to maximize the sum rate of small cell network. The main contributions of this letter are summarized as follows.

- The network model with load balance and power transfer is established.
- The scheme with load balance and power transfer is proposed to maximize the sum rate of the small cell network.
- A number of results are given to illustrate the better performance of our proposed scheme.

2. System Model

As shown in Fig. 1, consider downlink communication of small cell network, where $\mathcal{S} = \{1, 2, \ldots, s \ldots, \mathrm{S}\}$ SBSs with low transmit power are randomly and uniformly deployed in a circle area, and $\mathcal{N} = \{1, 2, \ldots, n \ldots, \mathrm{N}\}$ orthogonal frequency division multiple access (OFDMA) resource blocks (RBs) are equally allocated to SBSs. Assume small cell users (SUEs) are randomly and uniformly distributed in the coverage area of SBSs. Let $\mathcal{U} = \{1, 2, \ldots, u \ldots, \mathrm{U}\}$ denote the set of SUEs. For the resource allocation, assume different RBs are allocated to SUEs in the same small cell. Additionally, we assume fixed charing equipment, i.e., smart grid and charging pile provide limited energy $\mathbf{P}$ to the deployed SBSs

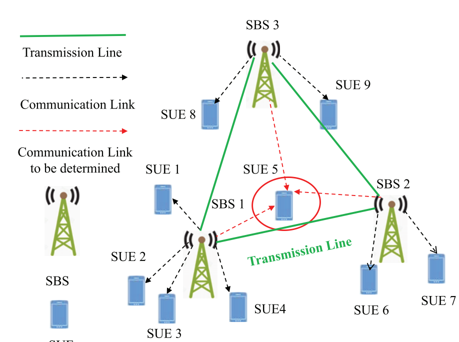

Fig. 1 Network model.

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[†]The author is with Electronics and Information Engineering, Changchun University of Science and Technology, No.7089 WeiXing Road, Changchun, Jilin, 130022, P.R.China.
[††]The author is with the State Key Laboratory of Integrated Service Networks (ISN), School of Telecommunications Engineering, Xidian University, No.2 South Taibai Road, Xi'an, Shaanxi, 710071, P.R.China.
a) E-mail: pengxuefei2009@foxmail.com (Corresponding author)
b) E-mail: xfjl1213@sina.com

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Algorithm 1 Load Balance and Power Transfer Algorithm

Initialization: $\mathcal{L}_s = \emptyset(\forall s \in \mathcal{S})$, and set $s = 1, n = 1, u = 1$.
for $u = 1 : \mathrm{U}$ **do**
  $s^* = \min\{\mathcal{PL}_{s,u} | \forall s \in \mathcal{S}\}$
  $\mathcal{L}_{s^*} = s^* \cup \mathcal{L}_{s^*}$
  for $s = 1 : \mathrm{S}$ **do**
    Calculate $\| SBS_s - SBS_u \|$
  end for
end for
for $k = 1 : \mathrm{S}$ **do**
  if $\mathbf{L}_k > \mathbf{L}_{max}$ **then**
    Sort the SUEs associated with SBS k by decreasing distance, and denote the former $\mathbf{L}_{max}$ SUEs associated with SBS k as $\mathbf{L}_k^o$, $y_{k,u} = 1(u \in \mathbf{L}_k^o)$, R_k^u=$\log(1+\frac{p_{\mathsf{RB}}^k \cdot g_{ku}}{N_0})(u \in \mathbf{L}_k^o)$ and $z_{k,u} = 0(u \in \mathbf{L}_k^o)$. Besides, denote the last $\mathbf{L}_k - \mathbf{L}_{max}$ SUEs associated with SBS k as $\mathbf{L}_{k'}$, and $y_{k,u} = 0(u \in \mathbf{L}_{k'})$.
    for $u = 1 : (\mathbf{L}_k - \mathbf{L}_{max})$ and $u \in \mathbf{L}_{k'}$ **do**
      if $\mathsf{R}_{kv}^u > \mathsf{R}_{d^*k}^u$ **then**
        $\mathsf{R}_{kv}^u = \log(1+\frac{p_{kv} \cdot g_{ku}}{N_0})$, and $z_{k,u} = 1(u \in \mathbf{L}_{k'})$.
      else
        $d^* = \min\{\mathcal{PL}_{s,u} | \forall s \in (\mathcal{D}/\{y_{s,u} = 1\})\}$, $\mathsf{R}_{d^*k}^u = \log(1+\frac{p_{\mathsf{RB}}^{d^*} \cdot g_{d^*u}}{N_0})$, and $z_{d^*,u} = 1(u \in \mathbf{L}_{k'})$.
      end if
    end for
  end if
end for

during a period of time, and $p_{\mathsf{RB}}^s(\forall s \in \mathcal{S})$ is the transmit power of SBS s on one RB that equals to $\frac{\mathbf{P}}{\mathbf{L}_{max}}$, where $\mathbf{L}_{max}$ denotes the maximal number of traffic load, i.e., users that each SBS can support.

3. Load Balance and Power Transfer Scheme

Following, we will give the detail description about the process of load balance and power transfer, which is described in Algorithm 1. Firstly, we assume each SUE is associated with the SBS that has the smallest path loss, which means that SUE u will be associated with SBS s^* satisfying the following formula

$$s^* = \min\{\mathcal{PL}_{s,u} | \forall s \in \mathcal{S}\}. \tag{1}$$

Further, we can determine the number of users associated with SBS s as $\mathbf{L}_s(s \in \mathcal{S})$. We specify the maximum traffic load that each SBS can support (the maximum number of users is allowed to associate with each SBS) is $\mathbf{L_{max}}$. Therefore, if $\mathbf{L}_s > \mathbf{L_{max}}$, $\mathbf{L}_s - \mathbf{L_{max}}$ SUEs will not associate with SBS $s(\forall s \in \mathcal{S})$ in the first process of user association. Let binary vector $\mathbf{y}$ represents whether SUEs are associated with SBSs, whose element is an association indicator decision variable $y_{s,u} \in \{0,1\}$ denoting whether SUE u associated with SBS s, $y_{s,u} = 1$ if SUE u associated with SBS s, otherwise $y_{s,u} = 0$. Then, we can obtain the data rate of SUE u associated with SBS s as R_s^u=$\log(1+\frac{p_{\mathsf{RB}}^s \cdot g_{su}}{N_0})$, where g_{su} is the channel gain from SBS s to SUE u, p_{RB}^s is the transmit power of SBS s on one RB, and N_0 is the power of white gaussian noise.

There are still some SBSs overloaded after the aforementioned minimum path loss association method. To further save energy of the small cell network, we will decide the SUE of overloaded SBS is served by its original SBS through transferring power from the nearest underloaded SBS or offloaded to its nearest underloaded neighbor SBSs. For example, as shown in Fig. 1, SUE 5 is the the overloaded load of SBS 1, we will determine SUE 5 is served by its original associated SBS 1 through obtaining power from the nearest neighboured SBS 2 of SBS 1, or directly offloaded to its nearest underloaded SBS 2.

Case 1: The SUEs of overloaded SBS k is served by its original SBS through transferring power from the nearest underloaded SBS v of SBS k.

Assume optical transmission line is used to connect different SBSs, then the received power of SBS k obtain from its nearest underloaded SBS v can be denoted as follow

$$p_{kv} = p_{\mathsf{RB}}^v \cdot f_{kv}, \tag{2}$$

where f_{kv} is the power loss in the transmission line from SBS v to SBS k, and p_{RB}^v is the transmit power of SBS v on one RB. As the power loss model given in [4], [5], the power loss f_{kv} can be calculated as follows

$$f_{kv} = \mathsf{C} \cdot \| SBS_v - SBS_k \|, \tag{3}$$

where C is the power loss of per unit length, and $\| SBS_v - SBS_k \|$ is the Euclidean distance between SBS v and SBS k, i.e., the length of transmission line between SBS v and SBS k. Assume one RB of SBS v is also occupied by SBS k in the process of power transfer. Therefore, the data rate of SUE u can be denoted as $\mathsf{R}_{kv}^u = \log(1+\frac{p_{kv} \cdot g_{ku}}{N_0})$, where g_{ku} is the channel gain from SBS k to SUE u, and N_0 is the power of white gaussian noise.

Case 2: The SUEs of overloaded SBS is offloaded to their nearest underloaded neighbor SBSs.

We adopt expanded cell user association method to offload cell-edge SUEs in the overloaded small cells to their nearest underloaded neighbor SBSs, here, we denote the set of underloaded SBSs as $\mathcal{D}$, so the new associated SBS d^* of SUE u can be denoted as follows

$$d^* = \min\{\mathcal{PL}_{s,u} | \forall s \in (\mathcal{D}/\{y_{s,u} = 1\})\}. \tag{4}$$

In this case, the maximal number of SUEs offloaded to SBS $d^*(\forall d^* \in \mathcal{S})$ should be no larger than $\mathbf{L_{max}} - \mathbf{L}_{d^*}$. $\mathsf{R}_{d^*k}^u = \log(1+\frac{p_{\mathsf{RB}}^{d^*} \cdot g_{d^*u}}{N_0})$, where g_{d^*u} is the channel gain from SBS d^* to SUE u.

Then, we will decide to use the methods in Case 1 or Case 2 to serve the SUEs in the overloaded SBSs by the following criterion. If $\mathsf{R}_{kv}^u > \mathsf{R}_{d^*k}^u$, we will choose the method described in Case 1 to serve SUE u in the overloaded SBS k, i.e., SUE u in the overloaded SBS is served by its original SBS through transferring power from the nearest underloaded SBSs of its original associated SBS. Otherwise $\mathsf{R}_{kv}^u \le \mathsf{R}_{d^*k}^u$, we will choose the method described in Case 2 to offload SUE u in the overloaded SBS k to SBS d^*, i.e., the SUE of overloaded SBS k is offloaded to their nearest underloaded neighbor SBS d^*

After the aforementioned process of load balance and power transfer described in Algorithm 1, we use vector $\mathbf{z}$ to represent the new association relationship between SBSs and SUEs for the SUEs belong to overloaded SBSs in the first process of user association, where $z_{s,u} = 1$ if SUE u is associated with SBS s, otherwise $z_{s,u} = 0$. Thus, the sum data rate of SUEs deployed in small cell network can be expressed as follows

$$\mathsf{R}_{sum} = \sum_{u \in \mathcal{U}} \sum_{s \in \mathcal{S}} \mathsf{R}_s^u \cdot y_{s,u} + \sum_{u \in \mathcal{U}} \sum_{s \in \mathcal{S}, d \in \mathcal{S}} \mathsf{R}_{sd}^u \cdot z_{s,u}. \quad (5)$$

4. Complexity Analysis

The calculation of the distances among SBSs, and SBSs and SUEs has a complexity $O(\mathrm{S}^2)$ and $O(\mathrm{SU})$, respectively. Moreover, SUEs are associated with the SBSs nearest to them, which has a computing complexity of $O(\mathrm{SU})$. Following, the SBSs have overloaded loads will be offloaded according to the criteria given in Case 1 or Case 2, which has a computing complexity not larger than $O(2\mathrm{SU})$. Therefore, the total computing complexity of the proposed algorithm is not larger than $O(\mathrm{SU}*\mathrm{S}^2*\mathrm{SU}*2\mathrm{SU})$=$O(2\mathrm{S}^5\mathrm{U}^3)$.

5. Simulation Results

In our simulation, all the SUEs and SBSs are randomly and uniformly distributed in a circle region, and the radius of R is given in meters. We consider the channel model includes path loss, rayleigh and shadowing fading, where the path loss from SBS s to SUE u is given by $\mathsf{PL}_{su} = 38.46 + 20 * log10(d_{su})$, in which d_{su} denotes the distance between SBS s and user u, with the unit m. The shadowing standard deviations is 8 dB for the link between SBS and the SUE [12], and C is equal to 0.05 W/m. In addition, $\mathbf{L}_{max}$ is set as the maximum integer not larger than the ratio of the number of users and the number of SBSs. Next, we compare the proposed scheme with the load balance scheme that does not consider power transfer among SBSs as studied in [11], and power transfer scheme.

Figure 2 shows the sum rate with respect to the number of users, where S = 3, R = 15 m, and p_{RB} = 10 W. The number of deployed SUEs varies from 9 to 21. Moreover, $\mathbf{L}_{max}$ varies from 3 to 7 corresponding with the number of deployed SUEs varies from 9 to 21. We can observe the sum rate of the proposed scheme increases with the increasing of the number of deploying SUEs. Moreover, the sum rate of the proposed scheme is better than the load balance scheme and power transfer scheme used independently. The reason is that the proposed scheme choose either load balance or power transfer method that can achieve a higher rate to serve the overloaded SUEs.

Figure 3 shows the sum rate varies with the transmit power of SBSs, where S = 3, R = 15 m, U = 15, $\mathbf{L}_{max}$ = 5, and the transmit power p_{RB} of each SBS varies from 5 W to 25 W. We can observe the sum rate of the three schemes

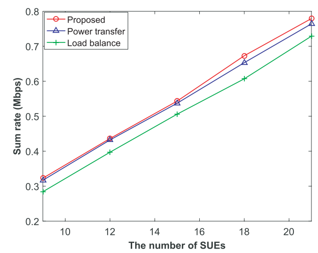

Fig. 2 Sum rate varies with the number of SUEs

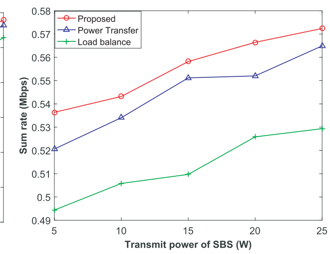

Fig. 3 Sum rate varies with transmit power of SBSs

increase with p_{RB}. The reason is that the higher transmit power can provide better quality of service. Besides, the sum rate of the proposed scheme is better than the other two schemes because the proposed scheme jointly consider load balance and power transfer factors.

6. Conclusion

A scheme with both load balance and power transfer among SBSs has been proposed in this letter to maximize the sum rate of small cell network. Firstly, SUEs have been associated with their nearest SBSs. There are still some SBSs overloaded since the limited load supporting ability of SBSs. Therefore, the proposed scheme considering both load balance or power transfer has been adopted to serve the overloaded SUES in a higher sum rate secondly. Finally, numerical simulations have been given to demonstrate the better performance of the proposed scheme.

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