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Research on Resource Allocation based on Clustering in Femtocell Networks

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Abstract

Aiming at the problem that existing femtocell base station searching the optimal clustering scheme based on the clustering resource allocation algorithm is complex. We propose that building an conflict graph and adjacency matrix before clustering to calculate the number of clusters needed for FBS group by using the adaptive clustering heuristic algorithm. We follow maximization the sum of the FBS distances in the cluster and group the femtocell base stations to narrow the search range to reduce the computational complexity. In order to achieve different business types service, based on the above clustering algorithm, this paper proposes a new method that using the weighted energy efficiency, which including the user interruption and the network spectral efficiency as a fitness function of the power control scheme to solve the problem. The simulation results show that the same rate requirement reduces the complexity, while the same complexity increases the user's average rate.

Key words: *femtocell, clustering, power control, resource allocation*

1. Introduction

The coverage to indoor users have a vital role on the performance of wireless communication because of the fact that the 70% demand of users in the wireless communication focus on indoor area. To cover indoor area by macro station, the electromagnetic wave needs to penetrate walls, causing serious attenuation, so the indoor communication needs to improve the covering effect. Femtocell technology employing indoor access points to cover, received extensive attention in the industry [1-3] due to the excellent indoor coverage effect and the characteristics of low power consumption and low cost.

However, because of sharing wireless channel, wireless resource in wireless communication is precious. The resource allocation has become a very important research direction. Currently existing femtocell resource allocation technology is mainly divided into three categories: pure spectrum allocation, power control and the co-allocation of the spectrum and power. The characteristic of pure spectrum allocation technology is the efficiency of spectrum utilization can be improved by inhibiting interference between the femtocell. The basic idea of power control is considering the tradeoff between network coverage and interference. The co-allocation of spectrum and power can improve the spectrum efficiency and energy of the network at the same time. The spectrum allocation of the fixed transmission power does not implement the energy saving of the network. The network spectrum efficiency of the power allocation without spectrum reuse is low. Due to the fact that network spectrum efficiency can be improved under the condition of network energy efficiency by co-allocation of spectrum and power. Therefore an effective spectrum and power allocation mechanism is required to promote the network performance. But under the condition of satisfying user’s quality of service, the oversize transmission power of FBS (Femtocell Base Station, FBS) will cause energy waste. While reducing the transmission power can reduce energy consumption, but it is likely to reduce the QoS of users and improve network outage probability. Obviously, the suitable downlink transmitted power configuration of FBS is the key technology to improve the network efficiency under the condition of satisfying the QoS of users.

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The clustering is used by existing technology to resource allocation. Clustering is an effective management method of interference, it can reduce the femtocell interference in the same layer, and separate the whole network resource allocation problem into several clusters in resource allocation problems, to reduce the difficulty of spectrum allocation and power control. Through the clustering to reuse frequency in femtocell network, increase downlink transmission power of femtocell does not necessarily cause interference to the adjacent femtocell, because the orthogonal spectrum is used by large interference of femtocell.

But the scope of the search for the optimal clustering scheme of existing femtocell clustering algorithms is extensive, which lead to high computational complexity, due to the fact that the grouping is not executed before clustering femtocell. In the genetic algorithm based femtocell power control scheme, which consider the energy efficiency as the objective function, increasing the outage probability is the expense to improve the energy efficiency of network, and only for single user business.

Therefore, in this paper femtocell clustering algorithm and power allocation scheme in the network is researched. In view of the large computational complexity in existing clustering algorithm of the femtocell, we propose the grouping femtocell according to conflict graph and adjacency matrix in front of the clustering to shrink search scope of the optimal clustering scheme to reduce the computational complexity of clustering algorithm. Aim at the problem that in the existing femtocell power control scheme, increasing the outage probability is the expense to improve the energy efficiency of network, and only for single user business, we comprehensive consider the user interrupt problem, different business requirements and the network spectrum efficiency weighted energy efficiency as the fitness function, to ensure power adjustment without disrupting users communication, adapting different business needs, while improving energy efficiency both users QoS of power control. Therefore, the reasonable mathematical model for the rational design of clustering mechanism of resource allocation is needed.

2. Mathematical Model

Define optimize network efficiency as the objective functions of the resource allocation:

$$\begin{aligned}
&\max_{\Gamma^n_{k,f},\mathrm{P}_f} \sum_{l=1}^{|\mathbf{C}|}\sum_{f\in \mathrm{C}_l} \frac{\sum_{n=1}^{\mathrm{N}}\sum_{k=1}^{\mathrm{K}_f}\Gamma^n_{k,f}\Delta f\log_2(1+\mathrm{P}_f\Upsilon^n_{k,f})}{\mathrm{P}_{f_in}} \\
&s.t.\quad \mathrm{C1}: \sum_{n=1}^{\mathrm{N}}\Gamma^n_{k,f}\Delta f\log_2(1+\mathrm{P}_f\Upsilon^n_{k,f}) \ge \mathrm{R}_{k\min}, \forall k \\
&\qquad \mathrm{C2}: \Gamma^n_{k,f}\in\{0,1\}, \forall n,k,f \\
&\qquad \mathrm{C3}: \sum_{k=1}^{\mathrm{K}_f}\Gamma^n_{k,f}=1, \forall n,k,f \\
&\qquad \mathrm{C4}: \bigcup_{l=1}^{|\mathbf{C}|}\mathrm{C}_l=\mathbf{F};\ \mathrm{C5}: \bigcap_{l=1}^{|\mathbf{C}|}\mathrm{C}_l=\varnothing \\
&\qquad \mathrm{C6}: \mathrm{P}_{\min}\le \mathrm{P}_f\le \mathrm{P}_{\max}, \forall f
\end{aligned} \tag{1}$$

Where, Δf is the bandwidth of the channel; P_f is transmitted power of FBS f ; $\Upsilon^n_{k,f}$ is user kth of FBS f^{th} on the n^{th} sub-channels SINR ; If the n^{th} sub-channel is assigned to the k^{th} users in the f^{th} FBS, $\Gamma^n_{k,f}=1$, otherwise, $\Gamma^n_{k,f}=0$; when the transmitted power is P_f , P_{f_in} is FBS actual need to consume power, we have:

$$\mathrm{P}_{f\_in}=\mathrm{P}_0+\Delta_\mathrm{P}\mathrm{P}_f \tag{2}$$

Where, P_0 is 10.1W, Δ_P is 15.

C1 means each user's data rate shall not be less than demand rate; C2 means value of $\Gamma^{n}_{k,f}$ is 0 or 1; C3 means for any femtocell, each channel can only be assigned to a user; C4 means the whole cluster constitute a femtocell set F; C5 means femtocell is not repeated in different clusters; C6 means the scope of FBS transmission power.

Both continuous variables and discrete variables are included in above optimization problem, which is a mixed integer nonlinear programming. The computational complexity of this problem is large and exponential increase with the number of FBS increasing. In order to simplify and solve the above problems, the resource allocation problem is divided into two steps, to avoid mixed integer nonlinear programming. To solve this problem by these two steps into two sub-problems: the clustering problem to reduce the complexity and sub-channels allocation and power allocation problem.

2.1. Clustering

For femtocell base station network, the goal of the clustering is to assign FBS which is close and larger interference to different clusters to use different spectrum so as to improve the spectrum utilization of the network, and makes the sum of the largest cluster of FBS in distance in order to reduce interference so as to improve the spectrum utilization efficiency of resources of the network. Therefore, clustering objective function can be expressed as Equation (3).

$$\begin{aligned} &\max \sum_{l=1}^{|\mathbf{C}|} \sum_{f, f_0 \in \mathrm{C}_l, f \neq f_0} d_{f,f_0} \\ &s.t.\ \ \mathrm{C1}: d_{f,f_0} - \mathrm{R}_{th} > 0 \\ &\qquad \mathrm{C2}: \bigcup_{l=1}^{|\mathbf{C}|} \mathrm{C}_l = \mathbf{F} \\ &\qquad \mathrm{C3}: \bigcap_{l=1}^{|\mathbf{C}|} \mathrm{C}_l = \varnothing \end{aligned} \tag{3}$$

Where , d_{f,f_0} is the distance between the femtocell f located in (x_f, y_f) and femtocell f_0 located in (x_{f_0}, y_{f_0}) ,we have $d_{f,f_0} = \sqrt{(x_f - x_{f_0})^2 + (y_f - y_{f_0})^2}$. In order to avoid collision, any two femtocell with of the distance less than R_{th} must be assigned to different clusters.

In order to solve the above optimization problem, the clustering algorithm is proposed according to the interference figure and adjacency matrix for grouping femtocell in front of the clustering.

(1) The construction of conflict graph

According to the definition of the graph theory [4], femtocell interference figure can be represented by G=(V, E), among them, V is vertices set , E is edge set. The femtocell f in $\mathbf{F}$ one to one correspondence with the vertices in the graph $\mathrm{v}_f, \forall f \in \mathbf{F}$. E is edge between vertices v_f and v_{f_0} with $\mathrm{e}(\mathrm{v}_f, \mathrm{v}_{f_0}), \forall f, f_0 \in \mathbf{F}$, reflects the femtocell collision relations between the interference. Specifically, if the distance between the femtocell f and femtocell $f_0 (f \neq f_0)$ is less than R_{th}, that means the interference between them is larger, there is boundary $\mathrm{e}(\mathrm{v}_f, \mathrm{v}_{f_0})$ between corresponding vertex v_f and v_{f_0} .

Assume that there are six FBS in the network of femtocell, and $d_{12}, d_{23}, d_{13}, d_{45} < \mathrm{R}_{th}$. When the femtocell distribution as shown in figure 1, the corresponding conflict graph is shown in Figure 2.

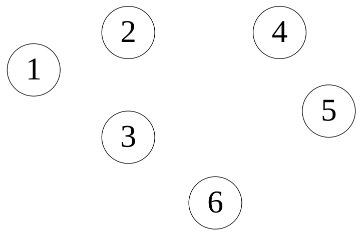

Figure 1. The distribution of femtocell

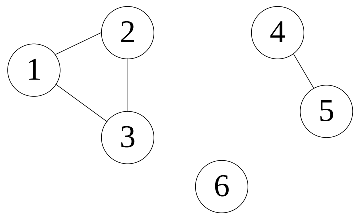

Figure 2. The conflict graph of femtocell

Because of there is no interference between FBS and its attribution FUE, there is no loop in the conflict graph. $d_{\mathrm{G}}(v_f)$ is the degree of vertex v_f. V in the vertex has the following properties.

Property 1 If $d_{\mathrm{G}}(v_f)=0$, vertex v_f is isolated point, which means that there is no collisions interference between corresponding femtocell and any other femtocells.

Property 2 If $d_{\mathrm{G}}(v_f)\neq 0$, that is collision interference between femtocell f and femtocell corresponding to the vertexes connected with vertex v_f. The bigger $d_{\mathrm{G}}(v_f)$ is, the bigger the femtocell f collision distractions.

(2) The construction of adjacency matrix

To express quantitatively the conflict graph G, construct adjacency matrix $\mathbf{A}(\mathrm{G})=[a(v_f,v_{f_0})]_{v_f,v_{f_0}\in \mathrm{V}}$. Specially, if $d_{f,f_0}<\mathrm{R}_{th}$, $a(v_f,v_{f_0})=1$, or $a(v_f,v_{f_0})=0$.

For conflict graph shown in Figure 2, the adjacency matrix $\mathbf{A}(\mathrm{G})$ is:

$$\begin{bmatrix} 0 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

(3) Clustering

Clustering [5] goal is to divide the vertices connected in interfere figure into different clusters, makes femtocells have interfere collision relationship use different sub-channels.

2.2. Sub-channel and Power Allocation Sub-problem

(1) Sub-channel allocation [6]

First of all, according to the number of clusters to differentiate frequency band, distribute orthogonal spectrum for different clusters. Due to there is no interference between femtocell within the cluster, the cluster is spectrum reuse unit, namely all femtocell within clusters use the same spectrum. It is beneficial to reduce the difficulty of the spectrum allocation, improve spectrum efficiency. It units of the In the communication system using resource block as unit, can put the total number of available resources block according to the number of clusters $|\mathbf{C}|$ group first, then assigned the different groups of blocks resources into different FBS.

Assume that each cluster of the available bandwidth is equal, for each FBS usable spectrum bandwidth:

$$\mathrm{B}=\mathrm{W}/|\mathbf{C}| \tag{4}$$

Where, W with the total bandwidth available for femtocell network.

According to the literature [8], within each femtocell, can allocate sub-channel by using Equation (5).

$$k_f(n) = \arg\max \frac{P_f \Upsilon_{k,f}}{G_{k,f}} \tag{5}$$

Where, $k_f(n)$ refers to n sub-channels assign to service users k of femtocell f.

(2) Power allocation

After frequency reuse between the FBS, due to large disturbance of femtocell using orthogonal spectrum, increase the FBS downlink transmition power does not necessarily cause disturbance to the adjacent femtocell, but under the condition of satisfying user's QoS, larger femtocell transmission power will cause energy waste. However, reduce the transmission power can reduce energy consumption, but it is likely to reduce the user's QoS, increase outage probability of network. Obviously, the appropriate FBS downlink transmition power configuration is on the premise of guarantee the quality of customer service is the key to reduce the network energy consumption, therefore, effective power control must be conducted on the basis of spectrum allocation.

The existing power control scheme based on genetic algorithm use the energy efficiency as fitness function:

$$EE_f = \frac{\sum_{k=1}^{K_f}\sum_{n=1}^{N} \Delta f \cdot C_{k,f}^n}{P_{f\_in}} \tag{6}$$

Where, EE_f is energy efficiency of femtocell f, defined as the ratio between femtocell throughput and FBS actual consumption power; Δf is the bandwidth of the sub-channel, which unit is Hz; $C_{k,f}^n$ is transmission capacity on the unit frequency band, can be obtained by truncation Shannon formula:

$$C_{k,f}^n = \begin{cases} C_{\min} & \Upsilon_{k,f}^n < \Upsilon_{\min} \\ \alpha \log_2\left(1+\Upsilon_{k,f}^n\right) & \Upsilon_{\min} < \Upsilon_{k,f}^n < \Upsilon_{\max} \\ C_{\max} & \Upsilon_{k,f}^n > \Upsilon_{\max} \end{cases} \tag{7}$$

Where, α is attenuation factor, means the signal attenuation in the process of actual transmission.

The fitness function of Equation (6) only considers the energy efficiency of the femtocell and in the process of power adjustment can reduce the user's QoS. In order to ensure that the user service is not interrupted, introduce the concept of weighted energy efficiency:

$$EE_{f\_w} = \begin{cases} 0 & P(\Upsilon_{k,f}^n < \Upsilon_{k\min}) > 0 \\ C_{f\_n} EE_f & else \end{cases} \tag{8}$$

Where, $P(\Upsilon_{k,f}^n < \Upsilon_{k\min}) > 0$ is the user's outage probability, suggests that when user's SINR is less than the threshold values $\Upsilon_{k\min}$, communication will interrupt. Because of the communication between the user's business is often not identical, according to the required transfer rate of users calculate user outage probability is more tally with the actual; C_{f_n} is the normalized unit frequency band transmission capacity:

$$C_{f\_n} = \frac{C_f}{C_{max}} \quad (9)$$

Where, C_f is femtocell f the average transmission capacity on the unit band:

$$C_f = \frac{\sum_{k=1}^{K_f} C_{k,f}}{K_f} \quad (10)$$

The advantage of introducing C_{f_n} as energy efficiency has weight avoiding the user in the process of power control by the user's transmission rate and the femtocell energy efficiency limit caused by communication interrupt.

Using weighted energy efficiency as an individual fitness function is to provide the safeguard for user communication interrupt. This is because when a user receives the signal SINR is too low and can't communicate, the attribution of FBS fitness value is 0, so that they can avoid some FAP because of the transmitted power is too small and not services. Therefore, employing the weighted energy efficiency in Equation (8) as an individual fitness function in power control can ensure users QoS in the premises of improving the efficiency of the network.

3. The femtocell in the network based on clustering of resource allocation mechanism

First of all, clustering the femtocelling; then, sub-channel and power allocation [9] within each cluster. Simplified flow chart of resource allocation scheme is shown in Figure 3.

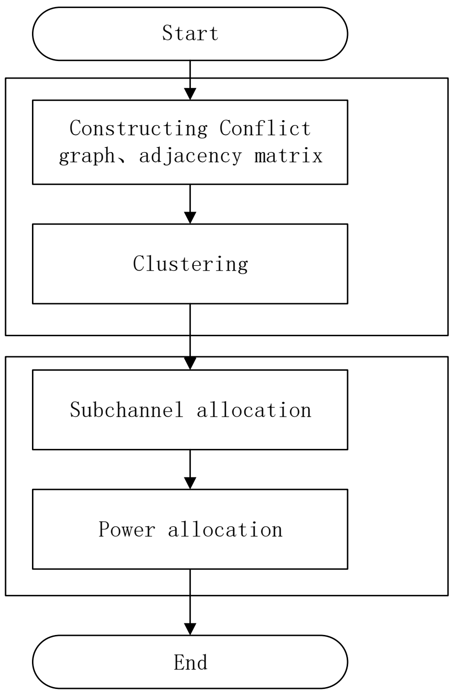

Figure 3. The resource allocation scheme based on clustering in femtocell networks

Based on the conflict graph and adjacency matrix clustering detailed steps are as follows:

Initialization initialize the cluster number $l(l \in \mathrm{Z}^{+})$ to 1; Y is isolated point set;

Step 1 Add all vertex with degree 0 to Y, and remove the vertices in V;

Step 2 If $\mathrm{V} = \varnothing$, add all the femtocell to clusters C_l ,and go to step 8, otherwise go to step 3;

Step 3 If $\mathrm{V} \neq \varnothing$, blocking the adjacency matrix, then each partitioned matrix corresponding to a FBS group, denoted as $\mathrm{G}_i(i = 1, 2, \ldots, w)$, which is the number of FBS group ,set the number of vertices in a FBS group $i(i = 1, 2, \ldots, w)$ for N_i;

Step 4 ACHA algorithm is used to clustering each FBS group, each of the FBS group clustering results are obtained, denote the required number of clusters for the i th a FBS group as L_i, $\max_i \mathrm{L}_i = |\mathbf{C}|$;

Step 5 Find any FBS group G_j with the number of clusters $|\mathbf{C}|$, according to the clustering results will step 4 vertices joined in this FBS group $|\mathbf{C}|$ in a cluster, and remove the vertices from the V, If $\mathrm{V} = \varnothing$, then go to step 7, otherwise go to step 6;

Step 6 If $\mathrm{V} \neq \varnothing$, there are $\mathrm{A}_{|\mathbf{C}|}^{\mathrm{L}_i}$ kinds of scheme of adding the vertex in the $i(i \neq j)$ FBS into $|\mathbf{C}|$ cluster. Based on the principle of largest FBS distance in cluster , choose the solution meet $\max \sum_{l=1}^{|\mathbf{C}|} \sum_{f, f_0 \in \mathrm{C}_l, f \neq f_0} d_{f, f_0}$, add the FBS group vertices corresponding clusters, and remove the vertices from the V, if $\mathrm{V} = \varnothing$,then go to step 7, otherwise repeat step 6;

Step 7 According to the type (11), add the first vertex of Y into the cluster $l^*(l^* \in \{1, 2, \ldots, |\mathbf{C}|\})$:

$$l^* = \arg\max_{f \in \mathrm{Y}} \sum_{f' \in \mathrm{C}_l} d_{f, f'} \tag{11}$$

Remove the vertices from the Y, if ,then go to step 8, otherwise repeat step 7;

Step 8 End of the clustering.

Clustering process as shown in Figure 4.

If the total number of FBS is F, for the clustering algorithms, which don’t grouping FBS in front of the clustering , clustering result can be obtained by a second Stirling number:

$$\sum_{i=1}^{F} \frac{1}{i!} \sum_{j=0}^{i} (-1)^{i-j} \binom{i}{j} j^F \approx O(F^F) \tag{12}$$

In this paper, the number of the clustering algorithm for clustering scheme may be:

$$\prod_{i=1}^{w} \mathrm{C}_{N_i}^{\mathrm{L}_i} \mathrm{A}_{|\mathbf{C}|}^{\mathrm{L}_i} \tag{13}$$

We can see, in this paper, the algorithm of the optimal clustering scheme greatly narrowed the search scope, thus reducing the complexity of clustering, and FBS in the network, the more the degree of complexity, the more obvious. According to the steps 4 and 7, the algorithm computational complexity is $O(F)$.

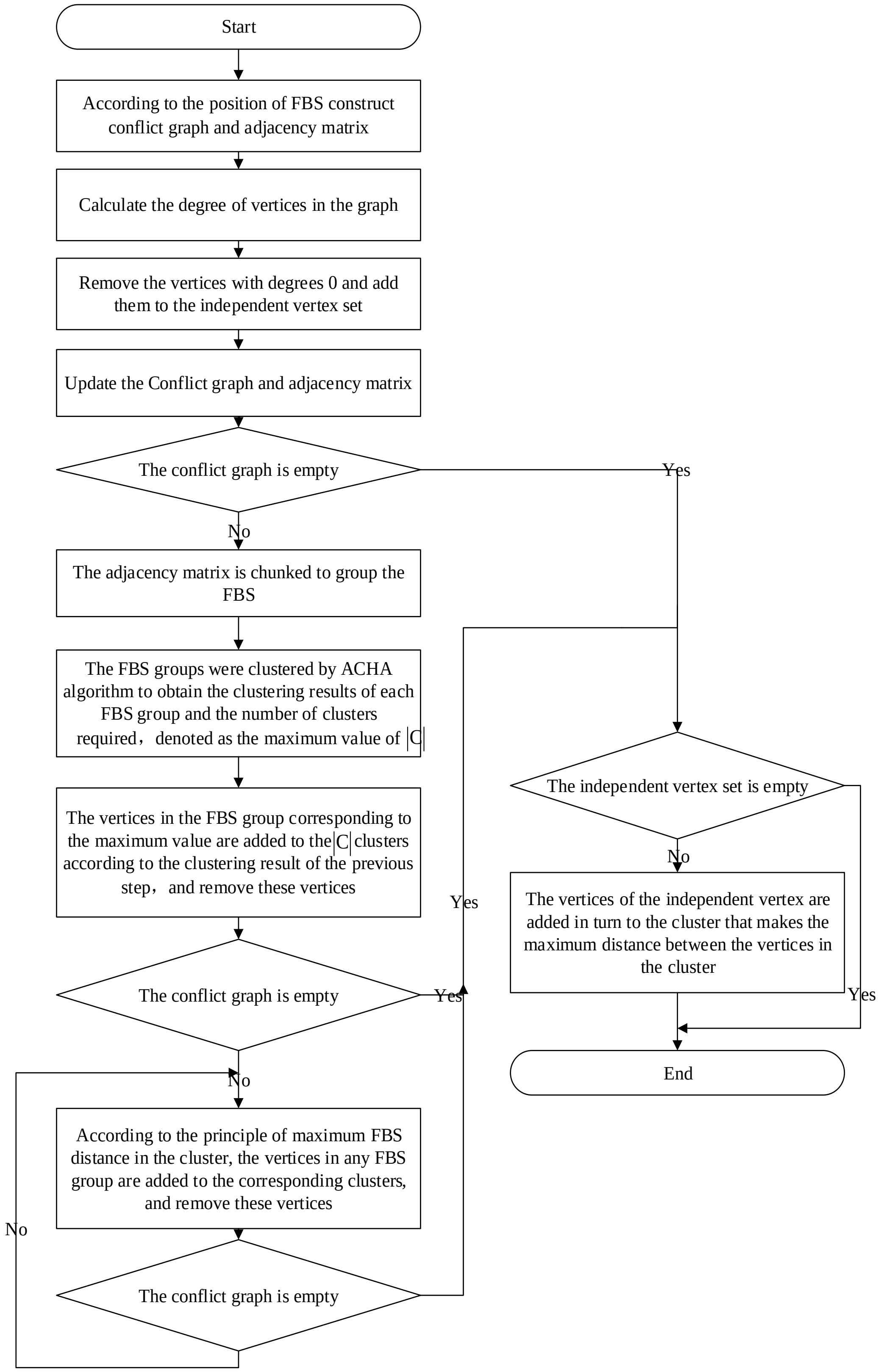

Figure 4. The femtocell base station clustering algorithm flow chart based on grouping

3. The Results of Simulation and Analysis

The MATLAB simulation parameters and parameter values as shown in Table 1.

Table 1. The System Simulation Configuration Parameters

The parameter name	Parameter values
MBS coverage radius(RM)/m	500m
FBS transmission power/ dB	46dB
FBS coverage radius(RF)/ m	50m
FBS maximum transmitted power(Pmax)/ dBm	20dBm
FBSminimum transmitted power(Pmin) /dBm	0dBm
Cmax/(bits/Hz), Cmin/ (bits/Hz)	4.4,0 bits/Hz
γ_{max}/dB γ_{min}/dB	19.5,-10 dB
The standard deviation of shadow fading σ / dB	8dB
The minimum coupling loss (MCL)/ dB	70dB
Attenuation factor (α)	0.6
The system total bandwidth (W)/ MHz	10MHz
AGWN unilateral power spectral density (N0)/ (dBm/Hz)	-174 dBm/Hz
Carrier frequency(f_c)/GHz	2 GHz
User noise factor/ dB	9 dB

In this section, compared with the high energy-efficient resource allocation scheme based on user QoS guarantees and the resource allocation scheme based on the UFR, the clustering algorithm that did not group the FBS before clustering, respectively.

(1) The the user average data rate of proposed resource allocation scheme based on clustering algorithm is compared with the user average data rate of the whole frequency multiplexing and the resource allocation scheme using the existing clustering algorithm.

As can be seen from Figure 5, with the increase in the number of FBS, the network average user data rate showed a downward trend. This is because the more FBSs, FUEs sufer from greater interference, SINR lower, the user data rate reduction. Compared to UFR, the average user data rate based on clustering [10] resource allocation is higher because clustering reduces the interference among with femtocells and increases the SINR of FUEs. In the case of low complexity of the algorithm, the clustering algorithm of this paper can obtain the average user data rate which is equivalent to the clustering algorithm which without grouping FBS before clustering.

(2) Compared with high energy-efficient power control based on user QoS guarantees and network energy efficiency and user average data rate based on energy efficiency power control.

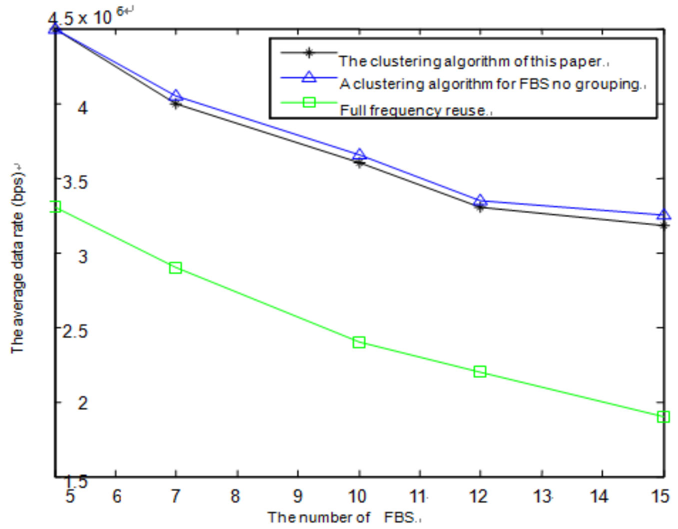

Figure 5. The average user data rate under different clustering algorithms

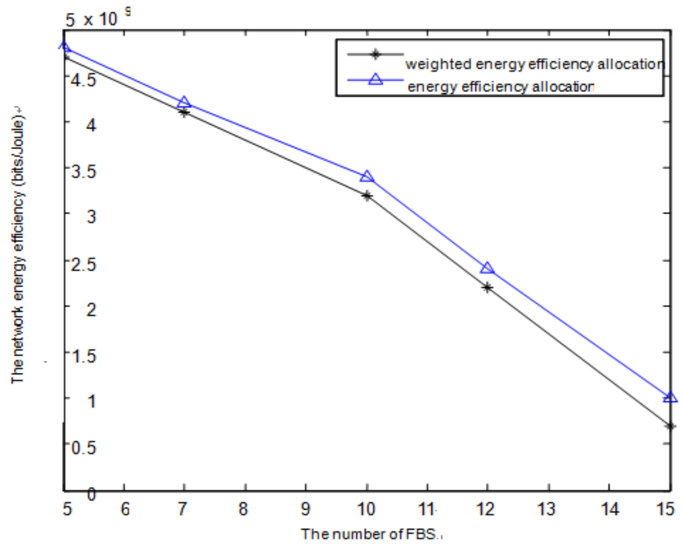

Figure 6. The network energy efficiency comparison under different power control scheme

As can be seen from Figure 6, with the increase in the number of FBS, the network energy efficiency is declining, because FBS is increasing, the network load is increasing, the base station needs to increase the power to expand coverage. Compared with the power control only based on energy efficiency, the network energy efficiency under the high energy efficiency power control based on user’s QoS guarantee is a bit low, because the system as much as possible to ensure the user’s QoS when it is making power adjustments to improve energy efficiency. Therefore, it can provide a higher average user data rate, as shown in Figure 7.

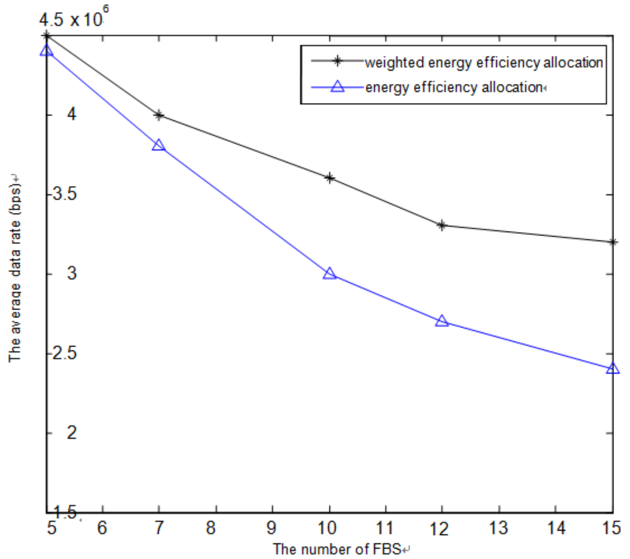

Figure 7. The average user data rate comparison under different power control scheme

4. Conclusion

Aiming at the problem that the complexity of the existing femtocell clustering algorithm is large, it is proposed to construct the conflict graph and adjacency matrix before clustering, and to block the adjacency matrix. The number of clusters required for each FBS group is calculated by using the adaptive clustering heuristic algorithm. The sum of the FBS distances in the cluster is maximized according to the principle of maximizing the sum of FBS distances in the cluster. In this paper, the clustering algorithm is used to reduce the search range of the optimal clustering scheme, so as to reduce the computational complexity of the clustering algorithm. Aiming at the problem that the improvement of the energy efficiency of the network under the power control scheme which at the expense of increasing the outage probability and the problem of the single service a power control scheme which based on the weighted energy efficiency as the fitness function to ensure that the user's communication is not interrupted, meet the different needs of business and improving network spectrum efficiency during the power adjustment process is proposed in this paper. According to the above-mentioned clustering algorithms and power control schemes, an energy-efficient resource allocation scheme based on user QoS guarantee is designed. The scheme first grouping for all femtocells to eliminate the same level of interference among the base stations and to improve the spectrum utilization of the network. Then dividing spectrum and advocating sub-channel according to the clustering results for the femtocell. Finally, power control for femtocell to improve the energy efficiency of the network. The simulation result shows that the average user data rate based on the clustering resource allocation scheme is higher than that of UFR. Compared with the clustering algorithm which does not grouping the femtocell before clustering, the proposed clustering algorithm can obtain the same average user data rate in the case of low computational complexity. Compared with the energy efficiency-based resource allocation scheme, the network energy efficiency of the two schemes is comparable, but the average user data rate of the energy-efficient resource allocation scheme based on user QoS guarantees is higher.

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