Clustering-based energy-saving algorithm in ultra-dense network

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Abstract. In Ultra-dense Networks (UDN), dense deployment of low power small base stations will cause serious small cells interference and a large amount of energy consumption. The purpose of this paper is to explore the method of reducing small cells interference and energy saving system in UDN, and we innovatively propose a sleep-waking-active (SWA) scheme. The scheme decreases the user outage causing by failure to detect users’ service requests, shortens the opening time of active base stations directly switching to sleep mode; we further proposes a Vertex Surrounding Clustering (VSC) algorithm, which first colours the small cells with the most strongest interference and next extends to the adjacent small cells. VSC algorithm can use the least colour to stain the small cell, reduce the number of iterations and promote the efficiency of colouring. The simulation results show that SWA scheme can effectively improve the system Energy Efficiency (EE), the VSC algorithm can reduce the small cells interference and optimize the users’ Spectrum Efficiency (SE) and throughput.

1 Introduction

UDN is one of the key technologies in the new generation mobile communication system, which can achieve the purpose of improving the system capacity and SE by densely deploying a mass of FAPs (Femtocells Access Points) [1]. But there is serious interference and energy consumption among a large number of dense Femtocells, so mitigating the inter-cell interference, saving network energy and improving the system performance has become some serious problems needed to be solved [2].

At present, many scholars have studied and explored the problems of interference among Femtocells and EE. Reference [3] proposes a User-oriented Graph based Frequency Allocation (UGFA) algorithm. In [4], a graph based low complexity dynamic clustering algorithm is proposed. The key thought of the algorithm in [4] is to divide the whole interference network into a number of clusters under the maximum intra-cluster interference and minimum inter-cluster interference and size constraint. Reference [5] proposes a joint colouring-based resource allocation and power reduction scheme in order to decrease interference while maintaining the network throughput. Reference [6] proposes a practically efficient energy saving algorithm based on switching-on/off scheme, which can be used in a distributed scene with low computational complexity. Reference [7] researches the optimal method of energy savings for femtocell clustering deployments with the sleep mode under macro-femto two-tier scenarios. Reference [8] investigates the UDN performance on both network SE and EE with sleep mode.
In this paper, we consider the problem of interference between the Femtocells network and large energy consumption in UDN, and we creatively put forward a kind of SWA scheme to decrease the energy consumption causing by the long opening time of FAPs, while avoiding FAPs occupy the spectrum resources and relatively enhancing the system efficiency. Aiming to figure out the interference problem in UDN, we further propose a VSC algorithm that can reduce the number of iterations and use the least kinds of colors to assign different colors for small cells.

2 System model

2.1 System model

In this paper, we consider a OFDMA downlink network which is densely deployed FAPs in UDN, as showed in Figure 1. System consists of a Macro Base Station (MBS) and F FAPs, which MBS is located in the center of system and F FAPs is randomly deployed under the coverage area of MBS. The distributions of FAPs and Femtocell User Equipments (FUEs) are two independent Poisson Point Process (PPPs), \( \Phi_F \) and \( \Phi_U \) with destiny of \( \lambda_F \) and \( \lambda_U \), respectively. The operation mode of FAPs can be divided into three modes: sleep mode, waking mode, active mode. We supposed that every FAP could accurately receive the channel state information (CSI) between FAPs and FUEs.

![System model](image)

Figure 1: System model

The Signal to Interference plus Noise Ratio (SINR) \( \gamma_{j,i,k} \) of FUE \( i \) with its serving active FAP \( j \) on subchannel \( k \) can be described as:

\[
\gamma_{j,i,k} = \frac{p_{j,k} \cdot \rho_{j,i,k}}{\sum_{n \neq j} p_{n,k} \cdot \rho_{n,i,k} + \sigma^2}
\]

The interference gain rate \( H_{j,k} \) of FUE \( i \) with its serving active FAP \( j \) on subchannel \( k \) can be described as:

\[
H_{j,k} = \sum_{n \neq j} \rho_{n,k} \cdot \rho_{n,i,k} + \sigma^2
\]

The transmission rate \( R_{j,i,k} \) of FUE \( i \) with its serving active FAP \( j \) on subchannel \( k \) can be described as:

\[
R_{j,i,k} = \Delta f \cdot \log_2 \left( 1 + \gamma_{j,i,k} \right) = \Delta f \cdot \log_2 \left( 1 + p_{j,k} \cdot H_{j,k} \right)
\]

where \( \Delta f \) is the network bandwidth, \( p_{j,k} \) is the transmission rate of active FAP \( j \) on subchannel \( k \) , as for sleep and waking FAPs, the transmission rate is setting as 0 .

2.2 Energy saving model
In order to improve the EE and SE of the system, we propose a novel energy-saving base station model, as shown in figure 2. The main idea of this model is to divide FAPs into three kinds of operating conditions: sleep, waking, and active. Where the sleep FAPs operate without any business, only minimal power is needed to maintain normal operation of the timer. Waking FAPs monitor the service requests, immediately turning to active mode to provide service for users as receiving the service requests. If there is no service request in a certain time, waking FAPs switch to the sleep mode in order to save energy. Active FAPs can provide the normal service for users and can handle the normal service request. If there is no business process in system, then turn to waking mode waiting for service request. The Timer1 in Figure 2 indicates the length of time that the FAPs has no service request in the waking state. When the system is busy, we need to increase Timer1. When the waking FAPs switch to sleep mode, Timer1 need to be reset based on the busy degree of system, and then open it in the next time while turning to waking mode. Timer2 indicates that the service monitoring time of sleep FAPs turning to waking mode. When the system is busy, we need to reduce Timer2. When FAPs is changed from sleep mode to waking mode, it is necessary to reset the Timer2 according to the system, and then open it when FAPs turn to sleep mode next time.

2.3 Analysis of EE
Supposed that the probability of active FAPs (nosleep) is $\eta$, so the probability of waking FAPs is $1 - \eta$, the density of the active FAPs, waking FAPs and sleep FAPs can be written as:

$$
\lambda_{BS\_sleep} = \lambda_B \cdot P_{sleep} = \lambda_B \cdot (1 + 3.5^{-1}(\lambda_u / \lambda_B))^{3.5} \tag{4}
$$

$$
\lambda_{BS\_active} = \lambda_B \cdot P_{active} = \lambda_B \cdot \eta \cdot (1 + 3.5^{-1}(\lambda_u / \lambda_B))^{3.5} \tag{5}
$$

$$
\lambda_{BS\_waking} = \lambda_B \cdot P_{waking} = \lambda_B \cdot (1 - \eta) \cdot (1 + 3.5^{-1}(\lambda_u / \lambda_B))^{3.5} \tag{6}
$$

A linear FAPs power model was given in [9] as:

$$
P_{fap} = \begin{cases} 
P_a & \text{Active} \\
P_w & \text{Waking} \\
P_s & \text{Sleep} 
\end{cases} \tag{7}
$$

where $P_a$ is the total power of active FAPs, $P_w$ is the power of circuit and cooling, and $\Delta P$ is the slope for the transmit power, $P_{fap}$ is the constant power of active FAPs, $P_a$ and $P_s$ denotes the power of maintenance for sleep mode.

We define EE $\eta_{ee}$ as the ratio between the sum of the network throughput and the sum of the BS power. Then the EE $\eta_{ee}$ of SWA in this paper can be described as:

$$
\eta_{ee} = \frac{\lambda_{B\_active} \cdot R}{\lambda_{B\_active} \cdot P_a + \lambda_{B\_sleep} \cdot P_s + \lambda_{B\_waking} \cdot P_w} \tag{8}
$$

3 VSC algorithm
3.1 VSC algorithm

![Interference topology graph](image)

Figure 3: Interference topology graph

We simplify the inter-cell interference in the coverage area of MBS as an interference topology graph, as shown in Figure 3. Each vertex in interference topology graph represents a small cell area covered by the active FAPs, the connection line (edge) between two vertices represents the interference between small cells. Interference topology graph is divided into several subgraph based on VSC algorithm. First, we color the bigger subgraph, and then turn to the smaller subgraph. VSC algorithm reduces the number of iterations, saves computing time, and further can use the colors as least as possible.

| Step | Description |
|------|-------------|
| 1    | The degree of each vertex in undirected graph is calculated, and the vertices are ordered in L_ver from large to small according to the degree of vertices; |
| 2    | Randomly select a color from the palette to color the vertex which have maximum degree in L_ver, the degree of that vertex will be removed from the L_ver after coloring; |
| 3    | The vertex with maximum degree is surrounded by some vertices which have the direct connection link with that vertex. (1) Unfold the surrounded vertices from the unconnected location, presented in horizon. The connected vertices are colored the different colors, the unconnected vertices are colored same colors; (2) After coloring, the used colors will be stored in L_col, and delete the corresponding vertex in L_ver; |
| 4    | Select color from the palette or L_col to color the vertex which has maximum degree in L_ver right now, goto Step3 until coloring all the vertices. |
| 5    | Then cluster the vertices, the vertices with the same color are divided into the same cluster. |

3.2 Analysis of clustering

![Clustering](image)
Figure 4: VSC algorithm

(a), (b) in figure 4 corresponds with Step2 in VSC algorithm, we select vertex3 whose degree is largest, and then randomly assign red to vertex3. (c), (d) in figure4 corresponds with Step3 in VSC algorithm, then we successively color green, blue, green, blue, green for vertex4, 1, 2, 6, 8; (e), (f), (g) in figure4 corresponds with Step4 in VSC algorithm, vertex7 has the maximal degree now, and only vertex5 surrounds vertex7, so assign blue for vertex5. So we can cluster the vertices according to same colors as: cluster \{1, 5, 6\}, cluster \{2, 4, 8\}, cluster \{3, 7\}.

4 Simulation Analysis

| Parameters                  | Value    |
|-----------------------------|----------|
| FAPs Max $P_{\text{Max}}/W$ | 0.05     |
| FAPs $P_s/W$                | 4.8      |
| FAPs $\Delta p/W$          | 8.0      |
| FAPs $P_f/W$                | 3.5      |
| FAPs $P_t/W$                | 2.9      |
| Radius of FAPs/m           | 10       |
| Radius of MBS/m            | 300      |
| System Bandwidth/MHz       | 20       |
| Density of FAPs $\lambda_g/m^2$ | 0.2 |
| $\eta$                     | 2/3      |

Table 2: Simulation parameters
Figure 5: EE of FAPs

Figure 5 shows the EE diagram of the FAPs with the increasing density of Femtocell density. EE in figure 5 shows an upward trend first, and then gradually decreases with the increase density of Femtocell. We can clearly find that the SWA scheme and DMCC algorithm have an optimal value of EE at 0.2 density of Femtocell. Sleep mode of small power base station is adopted by DMCC algorithm, which uses the min-cut scheme in graph theory to cut topological graph into some subgraphs so that the EE is high. SWA scheme introduce waking mode FAPs into system, which could avoid the FAPs directly turning from sleep mode to active mode, and use the smaller the iteration clustering algorithm to further promote the system EE. SWA scheme and DMCC algorithm compared to [10], EE increased by 30% approximately.

Figure 6: SE of FUEs

Figure 6 shows the Cumulative Distribution Function (CDF) of SE of average FUEs. As is shown in the figure 6, compared with DMCC algorithm and reference [11], the VSC algorithm can significantly improve the SE of the average FUEs. The VSC algorithm can effectively assign different colors to adjusted vertices, and can be dynamically changed according to the change of interference topology graph, while excellently eliminating inter-cell interference in UDN. SWA scheme saves the system spectrum resources through the different operation of FAPs and relatively improve the average FUEs SE.
Figure 7 shows the average FUEs throughput along with the change of density of FUEs. When the density of FUEs is 0-0.04m$^2$, the FUEs throughput of the DMCC algorithm is better than VSC algorithm, this is that the complexity of DMCC algorithm is low under low density of FUEs. But with the increase of the number of FUEs, the network computational complexity is much larger. While the VSC algorithm under the high-density FUEs, the clustering algorithm can also use fewer iterations. It is suitable for FUEs with high density, which is proper for UDN.

5 Conclusion
According to the shortcomings of the existed inter-cell interference and energy consumption in UDN, we make some great corresponding analysis and improvement. We innovatively proposes a SWA mechanism, which allows active FAPs that never receive service requests in a certain period of time switch to waking mode rather than directly turning to sleep mode, which avoids lots of energy consumption causing by the long time operation of FAPs and the occupation of spectrum resource for long time; VSC algorithm reduces the number of iterations of coloring. The simulations show that VSC algorithm with SWA scheme is more suitable for the actual ultra-dense network scenarios and has perfect improvement in EE and SE to some extent.

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