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Beijing Institute of Technology, Beijing, China
{liu_yu_zhou, laiwuwen2013}@bit.edu.cn

Abstract. Ultra-dense network (UDN) is considered as one of the key technologies of 5G. Due to the densification of base stations (BSs) and irregular topology of UDN, BS-centric schemes are usually accompanied by strong inter-cell-interference (ICI). In this paper, we propose a user-centric cluster resource allocation scheme (UCRA). In the proposed scheme, we take user experience into consideration and guarantee a desired signal-to-interference-plus-noise-ratio (SINR) for each user equipment (UE) by allocating orthogonal frequency resources to its major interference BSs. When allocating resources, we design an algorithm to seek a balance between system throughput and user fairness. Simulation results show the superiority of our scheme.

Keywords: ultra-dense network, user-centric, resource allocation, user experience, user fairness

1 Introduction

Due to the massive application of smart devices, mobile data traffic has been explosively increasing, which puts forward great challenges to the current wireless networks. Ultra-dense network (UDN) is a feasible and effective candidate solution [7].The basic idea of UDN is to get the access nodes as close as possible to the user equipment (UE). This can be achieved simply by the dense deployment of base stations (BSs) in the hotspots. However, UDN is a typically random network since BSs therein are deployed according to the traffic demands. Consequently, UEs in UDN usually suffer from severe inter-cell-interference (ICI).

Generally, methods of interference mitigation are divided into three categories [12]. The first one is to eliminate interference at the receiver. In [9], the authors analyze the performance of zero forcing receiver and minimum mean-square error receiver with successive interference cancellation under limited backhaul capacity. Notice that the interference signals in this cell have a similar structure to the desired signal because the interference signals are desired signals in their corresponding cell. In light of this, a simultaneous decoding strategy is proposed in [10]. However, the computational complexity of such methods hinders their application.

The second method is to adjust the transmission power of the signal dynamically to minimize the ICI. A channel state and interference-aware power allocation scheme based on non-cooperative Cournot model is studied in [3]. Focusing on the multi-user access issue in UDN with non-orthogonal multiple access, an efficient multi-user access scheme is proposed in [11]. However, dynamic adjustment of transmission power implies a complex scheduling algorithm adopted by BSs. Moreover, the receiver complexity increases with the number of UEs.

The third method is to allocate mutually orthogonal radio resources to the potentially interfering UEs so that interference can be avoided. In [1], an adaptive fractional frequency reuse resource allocation scheme is studied. In [4], an orthogonal sub-band assignment based on graph-coloring is proposed. Besides, a cluster-based two-stage resource management scheme based on the modified K-means algorithm is proposed in [8] and a coloring-based cluster resource allocation algorithm based on graph theory is studied in [2]. These schemes can be referred to as BS-centric schemes. However, the BS-centric methods are usually with strong ICI due to the densification of BSs and the randomness of UDN topology.

In this paper, we propose a user-centric cluster resource allocation scheme (UCRA). In our scheme, each UE and its cooperating BS constitute a virtual cell. We construct the interference graph based on graph theory, and the coloring algorithm is utilized to categorize UEs into several sets. When allocating resources, we seek a balance between user fairness and system throughput.The rest of this paper is organized as follows. The system model is given in section 2. In section 3, UCRA is stated in detail. Simulation results and analyses are presented in section 4. Finally, conclusions are drawn in section 5.

2 System Model

We focus on the downlink transmission with UCRA. Assuming an orthogonal frequency division multiple access (OFDMA)-based system and the available bandwidth is divided into several orthogonal resources, namely resource blocks (RBs).

We consider a channel model incorporating path loss and Rayleigh fading. Suppose UE m is served by BS p, the propagation gain G_p^m between UE m and its cooperating BS p on unit RB can be given as

$$G_p^m = (d_p^m)^{-\alpha} \cdot h_p^m, \tag{1}$$

where d_p^m and h_p^m are the distance and the exponentially distributed random variable between UE m and BS p, respectively. α denotes path loss exponent.

Similarly, the interference gain G_q^m between UE m and its interfering BS q on unit RB can be expressed as follows

$$G_q^m = (d_q^m)^{-\alpha} \cdot h_q^m. \tag{2}$$

We assume all BSs have the same transmission power P_0. The $SINR_m$ and the throughput T_m of UE m on unit RB can be expressed as

$$SINR_m = \frac{\sum_{p \subset Z_p} P_0 \cdot G_p^m}{\sum_{q \subset Z_q} P_0 \cdot G_q^m + \sigma^2}, \tag{3}$$

$$T_m = \log_2(1 + SINR_m), \tag{4}$$

where Z_p and Z_q are the set of cooperating BSs and interfering BSs for UE m, respectively. σ^2 is the variance of additional white gaussian noise (AWGN) on unit RB.

3 A User-Centric Cluster Resource Allocation Seheme

The UCRA includes two parts. In the first part, we construct the virtual cells and system interference graph. The second part is RBs allocation scheme.

3.1 Constructing the Virtual Cells and System Interference Graph

We assume each UE are serviced by its nearest BS and other BSs are in sleep mode. Besides, each UE and its cooperating BS constitute a virtual cell. The active BSs provide services for those UEs constituting virtual cells with them, and bring interference to others. The BSs in sleep mode do not provide services, nor do they interfere.

Taking user experience into consideration, the SINR of each UE should be above some threshold T_h. We can estimate its SINR based on (3) and compare it with the threshold T_h. If the value is above T_h, there is no severe interference for this UE. Otherwise, the UE suffers from severe ICI. Under this circumstances, it is necessary to find its interfering BSs and remove the largest one. This process goes on until the SINR surpasses the threshold T_h. By then, all the removed BSs are the major interfering BSs for this UE. For interference coordination, the UE is not allowed to share RBs with the UEs served by these BSs. Besides, if one BS serves multiple UEs, these UEs are not allowed to share RBs. To describe the relationship of interference in system, we construct an interference graph, in which each vertex represents a UE. There is an edge between two vertices when these UEs cannot share RBs.

Then, we consider the problem of categorizing UEs into several sets. The UEs in the same set can share RBs with each other. In the interference graph, UEs can share RBs if there is no edge between them. Otherwise, they are not allowed to share RBs. Therefore, we can formulate the UE categorization problem as a graph coloring problem. Given an undirected connected graph and some different colors, using these colors to render the vertices in graph and each vertex has one color. Finding a coloring method that makes every two adjacent vertices in the graph have different colors.

Due to the finiteness of orthogonal resources in OFDMA system, we hope the RB can be shared by more UEs to maximize the utilization of the RB. Therefore, we hope the number of sets as small as possible. The smaller the number of sets, the greater the number of UEs in some sets. We utilize the coloring algorithm, which seeks to solve graph coloring problem with the least number of colors. The vertexes with same color means they can share RBs while vertices with different colors are not. Then we can categorize UEs into several sets $\boldsymbol{\Psi} = \{\Psi_1, \Psi_2, \cdots, \Psi_C\}$ based on the color, where C is the number of colors needed in coloring algorithm.

3.2 RBs Allocation Scheme

Utilizing the coloring algorithm, we categorize UEs into several sets. Different from average allocation scheme, which allocates resource equally to each set, we consider an optimizing scheme taking account of the balance between system throughput and user fairness.

For system throughput, we consider the current average throughput of virtual cell $T_A^{'}$ as the evaluation indicator.

$$T_A^{'} = \frac{\sum_1^M T_i^{'}}{M} = \frac{\sum_1^M k_i \cdot T_i}{M}, \tag{5}$$

where M is the number of UEs. $\boldsymbol{T^{'}} = \{T_1^{'}, T_2^{'}, \cdots, T_M^{'}\}$ is the current throughput of each virtual cell. $\boldsymbol{k} = \{k_1, k_2, \cdots, k_M\}$ is the number of RB assigned to each cell. $\boldsymbol{T} = \{T_1, T_2, \cdots, T_M\}$ is the throughput of each UE on unit RB.

In our scheme, we seek user fairness on throughput for each UE. Therefore, we consider $(T_A^{'} - T_x^{'})$ as the evaluation indicator for user fairness, where $T_x^{'}$ is the throughput of the current minimum throughput cell (Marked as cell x).

To achieve this, we should maximize $T_A^{'}$ while minimize $(T_A^{'} - T_x^{'})$. Combining both, the optimization problem can be formulated by

$$\begin{aligned} \max_{\boldsymbol{k}} f(\boldsymbol{k}) &= \max_{\boldsymbol{k}} [T_A^{'} - w \cdot (T_A^{'} - T_x^{'})] \\ &= \max_{\boldsymbol{k}} [(1-w) \cdot \frac{\sum_1^M k_i \cdot T_i}{M} + w \cdot k_x \cdot T_x], \\ s.t. \qquad & k_i \geq 0,\ k_i \in Z,\ i = 1, 2, \cdots, M; \\ & \sum_1^C k_j^{'} = K, k_j^{'} \geq 0,\ k_j^{'} \in Z,\ j = 1, 2, \cdots, C. \end{aligned} \tag{6}$$

where w $(0 < w < 1)$ is a weighting factor. $\boldsymbol{k^{'}} = \{k_1^{'}, k_2^{'}, \cdots, k_C^{'}\}$ is the number of RB assigned to each UE set. K is the number of RBs in total.

The optimal solution is hard to find since it is a combinatorial optimization problem. Therefore, we design an algorithm and its main idea is presented as follows.

According to $\boldsymbol{T} = \{T_1, T_2, \cdots, T_M\}$, we can know allocating one RB to which UE set (Marked as set Ψ_Y) can we get the maximum throughput gain. When allocating one RB, we should assign it to set Ψ_Y for system throughput. For user fairness, we should assign it to the set Ψ_X where the cell x is in. When allocating each RB, we compare the schemes of allocating RB to set Ψ_Y and allocating RB to set Ψ_X, and choose the scheme of which the $f(\boldsymbol{k})$ is bigger. The detailed steps about RB allocation scheme is given in Algorithm 1.

Algorithm 1 can be interpreted as a “quantized version” of the gradient ascent algorithm. $f(\boldsymbol{k})$ is the function what we need to maximize. The number of RBs assigned each time corresponds to the learning rate, which determines the length of each step along the gradient. In the process of each gradient rising iteration, we compare scheme Y and scheme X to find which scheme makes $f(\boldsymbol{k})$

Algorithm 1 RBs allocation scheme

```
Initialization:
    $\boldsymbol{\Psi} = \{\Psi_1, \Psi_2, \cdots, \Psi_C\}$: Sets of UEs categorized by coloring algorithm
    $\boldsymbol{T} = \{T_1, T_2, \cdots, T_M\}$: Throughput of each UE on unit RB
    $\boldsymbol{k} = \{0, 0, \cdots, 0\}$: Number of RB assigned to each cell
    $K$: Number of RBs in total
Preparation:
    Making each set $\boldsymbol{\Psi} = \{\Psi_1, \Psi_2, \cdots, \Psi_C\}$ has one RB. Then, $\boldsymbol{k} = \{1, 1, \cdots, 1\}$, Remaining $(K - C)$ RBs
    According to $\boldsymbol{T} = \{T_1, T_2, \cdots, T_M\}$,we know allocate one RB to which UE set (Marked as set $\Psi_Y$) can we get the maximum throughput gain
Main Iteration:
for $i = 1 : (K - C)$ do
    Calculating the current throughput of each virtual cell $\boldsymbol{T'} = \{T_1', T_2', \cdots, T_M'\}$, $T_j' = k_j \cdot T_j$, $j = 1, 2, \cdots, M$
    Knowing the current minimum throughput cell (Marked as cell $x$)
    For scheme Y (allocating one RB to set $\Psi_Y$), we calculate $f_Y(\boldsymbol{k})$
    For scheme X (allocating one RB to set $\Psi_X$ where the cell $x$ is in), we calculate $f_x(\boldsymbol{k})$
    if $f_Y(\boldsymbol{k}) > f_X(\boldsymbol{k})$ then
        We execute the scheme Y, allocating one RB to set $\Psi_Y$
    else
        We execute the scheme X, allocating one RB to set $\Psi_X$
    end if
end for
```

increases faster. In other words, we choose the scheme which make it easier to find the local maximum value of $f(\boldsymbol{k})$. Finally, the local maximum value we find is the global maximum value (up to a quantization error), because the $f(\boldsymbol{k})$ is a convex function.

4 Simulation Results

4.1 Parameters

We consider the Poisson Point Process (PPP) from stochastic geometry theory as the model of UDN [5]. We choose a two-dimensional 1000 square meters area, where BSs and UEs are both randomly and uniformly distributed, following PPP distributions with density parameters of λ_B and λ_U, respectively. In order to evaluate the performance of the UCRA, we compare it with BS-centric methods like AIA scheme [6] in terms of system throughput. Both have similar network scenarios and assumptions. The main parameters used in this paper are presented in Table 1.

Table 1. Simulation Parameters

Parameters	Value
BS Density λ_B	500 (/1000 Square Meters)
UE Density λ_U	[50:50:250] (/1000 Square Meters)
BS transmission power P_0	30 dBm
Path loss exponent α	3.5
Variance of AWGN on unit RB σ^2	0.01
Number of RBs in total K	100
RB bandwidth B	180 KHz

4.2 Simulation Results and Analysis

In Fig.1, the system throughput increase with the number of UEs because the RBs are shared by more and more UEs.

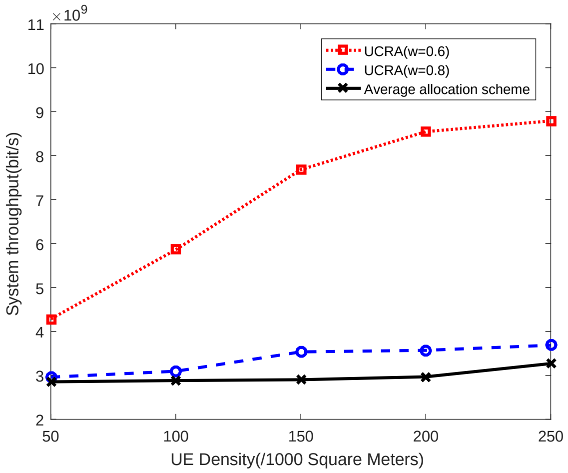

Fig. 1. System throughput vs. Number of UEs

In Fig.2, the throughput of minimum throughput cell decrease with the numbers of UEs. On the one hand, more and more BSs are being activated with the increase of UEs, which not only provide service but also bring interference. On the other hand, the number of RBs assigned to each UE will decrease due to the finiteness of orthogonal resources and the increase of UEs.

Besides, we compare our scheme in different value of weighting factor w with the average allocation scheme, which seeks fairness on RB for each UE sets. However, our scheme considers fairness on throughput for each UE. When w is 0.6, our scheme aims at system throughput rather than user fairness compared with average allocation scheme. When w is 0.8, our scheme has shown better performance in both ways due to the optimal allocation of RBs.

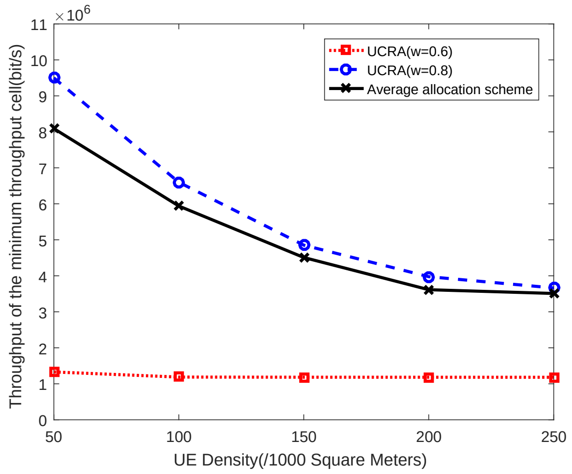

Fig. 2. Throughput of the minimum throughput cell vs. Number of UEs

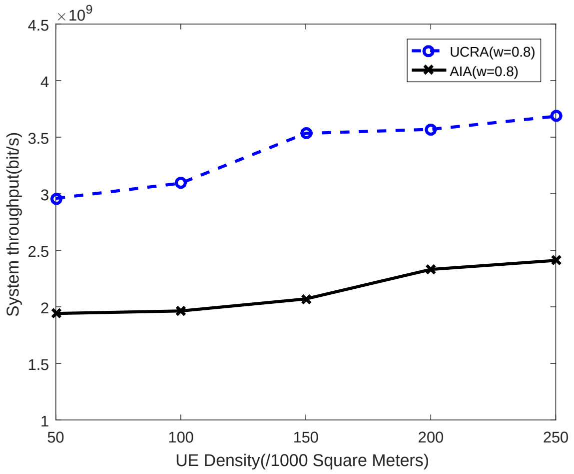

Fig. 3. System throughput vs. Number of UEs

From Fig.3, it is clear that our scheme performs better than AIA scheme in system throughput. Due to the densification of BSs and the randomness of UDN topology, BS-centric schemes like AIA usually perform worse in mitigating ICI. As a result, AIA scheme has lower throughput than that of UCRA.

5 Couclusion

In this paper, we propose a user-centric cluster resource allocation scheme (UCRA). In our scheme, each UE and its cooperating BS constitute a virtual cell. We take user experience into consideration and seek a balance between user fairness and system throughput when allocating resources. Simulation results have shown that our scheme outperformed the BS-centric scheme in terms of system throughput.

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