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Soft frequency reuse-based optimization algorithm for energy efficiency of multi-cell networks[☆]

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ABSTRACT

This paper studies the optimization problem of energy efficiency in multi-cell networks with multiple users such as 5G network. However, the spectrum allocation and inter-cell interference (ICI) in multi-cell networks are the important challenges. The Soft Frequency Reuse (SFR) scheme which manages the spectrum and reduces ICI is used to build SFR-cellular networks. We take the global energy efficiency of the SFR-cellular network as the objective function of the optimal problem to obtain the maximum energy efficiency. Unfortunately, the objective function is a non-concave function, which is significantly difficult to be solved directly. Therefore, we utilize the fractional program, successive convex approximation, Lagrange dual, and Karush–Kuhn–Tucker (KKT) conditions to transform the objective function into a concave function. In such case, we could solve the problem with the convex optimization method. Finally, based on SFR, we propose a global energy efficiency optimization algorithm to search for the optimal energy efficiency of networks. Simulation results show that the proposed algorithm holds the better performance.

1. Introduction

With the explosive growth of intelligent mobile terminals and mobile data traffic, operators need to improve the capacity of multi-cell networks such as 5G networks. The Orthogonal Frequency Division Multiple Access Technology (OFMDA), which holds the capacity of high throughput and anti-interference, has been used as the key technology in multi-cell networks to improve the spectrum utilization. However, with the increase of cell density and the decrease of frequency reuse factor in multi-cell networks, the inter-cell interference (ICI) becomes more and more serious, especially for the users located the cell edge. More importantly, the energy efficiency in multi-cell network has become an important challenge.

In order to overcome ICI and improve the spectrum utilization, the fractional frequency reuse (FFR) and SFR are proposed. FFR and SFR can improve the area spectral efficiency by changing the frequency reuse [1]. Qian et al. proposed an inter-cell resource allocation algorithm to maximize the throughput of the system [2]. Huang et al. introduced a new method of coordinated SFR for multi-cell networks to raise the throughput and reduce the outage probability [3]. The coverage probability and optimal SIR threshold for FFR and SFR had been derived in [4]. Sinh et al. studied the coverage probability in multi-cell networks [5]. They took the coverage probability as a function of the transmission ratio, FR factor, density of

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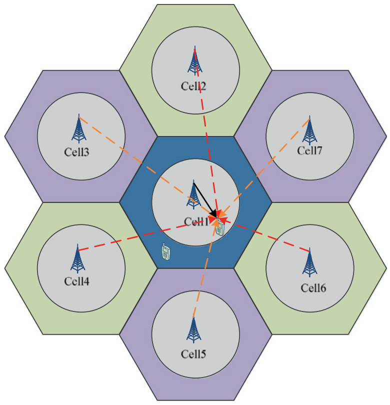

Fig. 1. The model of the SFR multi-cell network.

the base stations, and optimization factor. They envisioned that the trends of the coverage probability for the cell-edge users and cell-central users were opposite.

The energy consumption of wireless networks increases rapidly, especially for the base stations which consume most of energy [6]. How to improve the energy efficiency of wireless networks has become very important up to date. Some works have been done on the energy efficiency for networks. Xu and co-workers [7–10] had analyzed the energy efficiency performance with the SFR scheme in different networks. An algorithm was proposed to optimize energy efficiency of single-FFR-cell, with the maximum users' lowest rate requirement [7]. SFR was discussed for heterogeneous networks which deployed small cells [8–9], authors regarded that SFR could improve the system energy efficiency. Mahmud et al. had studied the relationship between energy efficiency and power amplification factor [10]. These methods carried the energy efficiency optimizations with SFR in a single cell or a mixed network structure with mutation SFR. However, the wireless network scale is very huge and the base stations interact with each other. The energy efficiency optimization in the single cell with the SFR scheme has many limitations. As mentioned in our previous work [11–13], energy efficiency has important impact on network performance. Thereby, the energy efficiency optimization for multi-cell networks is a practical problem.

In this paper, we study the optimization problem of energy efficiency in multi-cell networks with multiple users, which use the SFR technology. Firstly, we utilize SFR to construct a SFR multi-cell network. In this way, we can overcome the challenge of the spectrum allocation and inter-cell interference effectively in the multi-cell networks. Secondly, the global energy efficiency of networks is regarded as the objective function of the optimal problem. Using the optimal method, we can obtain the maximum energy efficiency of networks for the general optimal problem, while the objective function is non-concave in the case of multi-cell networks. The optimal solution to the problem is significantly difficult to be found. Thirdly, combining the integer relaxation, fractional program, successive convex approximation, Lagrange dual, KKT conditions, and sub-gradient iteration, we turn the objective function into a concave function. Accordingly, the convex optimization method can be used to solve the energy efficiency problem in multi-cell networks. Fourthly, based on SFR, we propose the global energy efficiency optimization algorithm to search for the optimal energy efficiency of networks. Finally, we carry out the sufficient simulation experimentations. Our simulation results show that the proposed algorithm holds the better performance.

The rest of this paper is organized as follows. Section 2 presents the system assumptions and model. In Section 3, we propose the mathematical model of energy efficiency in multi-cell networks and the corresponding optimal algorithm. Section 4 carries simulation analysis for the proposed algorithm. Finally, we conclude our work in Section 5.

2. Problem statement and system model

In this section, we discuss the multi-cell downlink OFDMA communication using SFR, where all the cells are regular hexagon in the fully-covered cellular network with SFR. Through using SFR, we turn a multi-cell network into a SFR-cellular network shown in Fig. 1. So, the SFR-cellular and the SFR multi-cell network are the same network. In this paper, we present some assumptions as follows:

- Each cell is divided into two parts: the cell-central area and the cell-edge area shown as Fig. 1. The total frequency bandwidth in each cell is B MHz, and it is divided into N sub-channels. All the sub-channels are divided into 3 categories shown as Fig. 2. The sub-channels which have the high-level transmit power, serve as the main frequencies and assign them to the cell-edge users. The main frequencies for the adjacent cells are mutually orthogonal, so the interference which received by the cell edge users from the neighboring cells will be weakened effectively. All the frequencies can be used by the cell-central users with the low-level transmit power.

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