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Joint tilt angle adaptation and beamforming in multicell multiuser cellular networks☆

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ABSTRACT

3D beamforming is a promising approach for interference coordination in cellular networks which brings significant improvements in comparison with conventional 2D beamforming techniques. This paper investigates the problem of joint beamforming design and tilt angle adaptation of the BS antenna array for maximizing energy efficiency (EE) in downlink of multi-cell multi-user coordinated cellular networks. An iterative algorithm based on fractional programming approach is introduced to solve the resulting non-convex optimization problem. In each iteration, users are clustered based on their elevation angle. Then, optimization of the tilt angle is carried out through a reduced complexity greedy search to find the best tilt angle for a given placement of the users. Numerical results show that the proposed algorithm achieves higher EE compared to the 2D beamforming techniques.

1. Introduction

Tilt angle adaptation which is also known as three dimensional beamforming (3DBF), full dimension multiple-input multiple-output (FD-MIMO) or vertical beamforming is a promising technology for interference management and performance improvement in fifth generation (5G) cellular networks [1,2]. In this technique by deploying active antenna systems (AAS) at the base station (BS) of cellular networks, it is possible to dynamically adapt the antenna tilt angle in each transmission interval [3]. This can be done by modifying parameters of symmetrical 3D pattern introduced in [4]. The antenna arrays radiates a fan-shaped beam with a large half power beam width (HPBW) in horizontal plane, while radiating a sharp beam with a small HPBW in the vertical plane which prevents signal from leaking to adjacent cells. In contrast to the horizontal plane in which the direction of antenna main lobe is fixed (since the BS orientation is fixed for each sector) , the antenna main lobe in the vertical plane can be steered to a desired direction by changing the tilt angle of the BS's antenna array [2]. To this end, we need information about users' locations and angle of arrival (AoA) at the BS. This tilt angle adjustment can improve some performance metrics such as spectral efficiency (SE), coverage probability or energy efficiency (EE) [1,2].

Most of the previous works on 3DBF study the problem of maximizing of the spectral efficiency in various scenarios. In [5] a game theory-based approach is proposed that maximizes the sum SE of a multi-cell network. In addition the authors approximate the signal-to-interference-plus-noise ratio (SINR) by its asymptotic value when the number of the BS antennas

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goes to infinity. In [6–8] the authors extract conditional ergodic sum SE of the network in terms of the BS antenna array tilt angle and then approximate it with complicated mathematical expressions. Hence the optimum tilt angles are found using exhaustive search over different possible tilt angles.

In general there are two 3DBF strategies: passive and active. In the passive 3DBF, the antenna pattern cannot be dynamically changed, and thus the antenna array tilt angle is fixed during several transmission intervals. This technique is suitable for applications like self organizing networks [9]. However in the active 3DBF, the antenna pattern can be dynamically changed i.e. the tilt angle is optimized by utilizing instantaneous user's location information and AoA in each transmission interval [2,3]. Thus, information about the users' locations is playing a vital role in designing of the 3DBF technique. The users' locations also can be modeled with the help of stochastic geometry (SG) [3,9,10]. To this end the users' locations is modeled by a uniform distribution and the BSs' are assumed to be located on the vertices of a hexagonal grid [10]. In addition, the BSs' locations can also be modeled with Poisson Point Process (PPP) [9]. Since the location of the users is a slow varying parameter, it can be estimated almost exactly and the assumption of knowing these informations is a reasonable assumption [5,11]. The subject of AoA estimation is well studied in literature [12]. Also there are some valuable works which concern with AoA estimation using novel low energy consuming machine learning approaches such as Bayesian compressive sensing algorithms [13,14]. Here similar to [3,5,8,11,15,22] we assume the information of the AoA of the users are accurately available at the BSs.

It is shown that the active 3DBF can achieve higher performance compared with the passive 3DBF since it adapts the antenna pattern to the instantaneous location of the users instead of using an average location of the users [2,3]. The problem of maximizing the sum SE in the active and passive 3DBF for a single cell network and two scenarios of single-user and multi-user is presented in [3]. Although in [3] potential of the 3DBF in performance improvement and advantage of active 3DBF over passive 3DBF are well studied, however because of the single cell arrangement the interference management property of the 3DBF is not fully exploited.

Although SE is a very important performance metric in the wireless networks, recently EE is also becoming more important from the network service provider's point of view. The 3DBF is one of the techniques that have been proposed to facilitate energy efficient communication in next generation of cellular networks. In this technique, by proper managing of interference and reducing the transmit power, the EE can be increased [2]. In spite of this fact, the problem of EE maximization by utilizing 3DBF has not been thoroughly investigated in the literature. In [9] by exploiting 3DBF, optimization of the sum EE in a two tier heterogeneous network (HetNet) is addressed.

In this paper, we investigate the problem of joint beamforming and tilt angle optimization at the BS antenna array for maximizing the total EE in a multi-cell multi-user network. In fact, on contrary to the previous works on 3DBF which have considered ergodic sum SE averaged over the users' locations, we investigate maximizing the total EE in a more realistic system with information on the users' locations in the BS. In addition, it is worthwhile to note that in all previous works simple linear beamforming such as eigen beamforming or zero-forcing beamforming were considered while we design the optimum beamforming vectors through a non-linear optimization problem. To the best of our knowledge, there is no similar work which jointly design beamfroming vectors and optimize tilt angle.

In addition, in our scenario the BSs cooperate with each other and share their channel vectors to each user. The objective function is total instantaneous EE subject to sum transmit power constraint at the BS. The resulting optimization problem is non-convex and therefore, a fractional programming approach is employed to convert it to a convex problem. To convexify this problem, Lemma 1 is introduced and then to solve the convex problem using block coordinate descent method, Theorem 1 is introduced. Also to reduce the complexity of searching for finding the optimal tilt angle, the clustering algorithm is proposed in Theorem 2.

Although the new problem is convex in terms of the beamforming vectors, it is still non-convex in terms of the tilt angle. To solve this problem, we divide the users into clusters and then in each cluster the optimum beamforming vectors are calculated. Finally, the optimum tilt angle is found according to the cluster in which the beamforming vectors maximize the total instantaneous EE. It will be shown that the optimal beamforming vectors are dependent on both users' elevation angle and channel gains. Simulation results demonstrate that our method outperforms the conventional 2D beamforming in which the antenna array pattern is omnidirectional and only precoding vectors are designed.

Rest of the paper is organized as follows. In Section 2, the system model and problem formulation are introduced. In Section 3, the proposed algorithm for solving the optimization problem is presented. In Section 4, the clustering algorithm is introduced. Simulation results are presented in Section 5. Finally, Section 6 concludes the paper.

In the paper scalars are denoted by lower-case letters. Vectors and matrices are denoted by bold-face lower-case and upper-case letters, respectively. $\prec$ stands for the generalized inequality. $(.)^H$ is the complex conjugate transpose. $\mathbb{E}\{.\}$ denotes statistical expectation and $||.||$ is the Euclidean distance (also known as $L^2 -$ norm). also $(.)^*$ represents the complex conjugate norm. I_M is the Identity matrix of size M and $\mathbb{C}^N$ is the $N-$dimensional complex vector space. In addition, a list of all variables that are used in our paper is given in Table 1.

2. System model

We consider a multi-cell network consisting of L cells. Each cell has K users that are uniformly distributed over the cell coverage region and a BS equipped with a linear antenna array consisting of M active elements. Each user is only served by its own cell's BS.