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Low complexity optimization for user centric cellular networks via large dimensional analysis

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ABSTRACT

Users near cell edges suffer from severe interference in traditional cellular networks. In this paper, we consider the scenario that multiple nearby base stations (BSs) cooperatively serve a group of users which is referred to as the cell free networks. A low complexity optimization method based on the large dimensional analysis is proposed. The advantage of the cell free networks is that the interference caused in the cell edge users can be converted into intended signal. It is not easy to obtain the optimal solution to the network due to coupled relations among the users' rates. To obtain a suboptimal solution, a precoder that balances signal and interference is adopted to maximize the network capacity. In traditional optimization, it requires instantaneous channel state information. We try to optimize the network sum rate based on the large dimensional analysis. In this way, the optimization can be transformed into another problem that merely depend on the large scale channel statistics. Large dimensional analysis is leveraged to derive the asymptotic signal to interference plus noise ratio that only depends on large scale channel statistics. Based on this result, the power allocation problem does not need to adapt as frequently as the instantaneous channel state information. By this means, signal exchange overhead can be greatly reduced. Numerical results are provided to validate the efficacy of the proposed optimization method.

1. Introduction

In order to cope with the exponential growth of wireless terminals and the data traffic demand, 5G network requires some advanced technologies in order to support the increased data rates requirements and the massive users' connectivity. In traditional cellular architectures, users suffers from intercell interference which is a main limiting factor for the network performance. One of the potential technologies that substantially improves the network performance is the network densification [1] and the corresponding technologies to promote such densification. Many additional base stations and access points are deployed in certain area so that the distances of users and BSs are reduced and the signal quality can be improved. However, the intercell interference can also be increased in the dense network. Inter-cell interference coordination [2] and cooperative communications [3] are some related methods that have been proposed to mitigate the interference. Another candidate technology is *massive MIMO* system [4,5], wherein large number of antennas is deployed in each BS. The number of antennas is much larger than that of users. The effect of intercell interference vanishes in this scenario. It can achieve better network performance regarding both spectral and energy efficiency [6].

An effective way to alleviate intercell interference is BS cooperation. The user can be simultaneously served by several nearby BSs. In this way the BS of other cell can transmit useful signal to the edge users. Since this form of cooperation does not restrict the user to be served by only one cell, we call it the user centric cell free network. More flexibility can be exploited such that the capacity performance can be improved.

The advantage of the network paradigm is that it can be implemented over the existing cellular networks. Since each user can be flexibly served by multiple BSs, the resource of the network can be efficiently assigned in the global network perspective. Better network performance can be achieved by properly design the precoding vectors for each user. The signal of a user is the combinations of signals from multiple BSs and it will cause interference to other users. So the joint optimization is needed among all the BSs, especially when the network scale is large. To tackle this problem, a heuristic precoding method is adopted, which balances the maximization of signal to the intended user and minimization of interference caused to other users [7].

The network capacity optimization for the cell free network needs global CSI and estimating the CSI consumes lots of resources, such as pilot training. Exchanging CSI among BSs requires strong backhaul links between the BSs and central control unit. It is not

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realistic in fast fading scenarios, in which the CSI would be easily outdated. The channel dimensions for each user is large thanks to the large scale antennas deployed in the BSs of massive MIMO scenarios. Under the Rayleigh fading case, the signal to interference and noise ratio (SINR) can be written as the function of large scale fading irrespective of the small scale fading.

In the large dimensional regime, the SINR is only related to CSI statistics. In this way, the power and parameter optimization for cellular networks can be performed based merely on large scale channel fading. The performance of large scale MIMO system has been extensively studied based on random matrix theory (RMT). In [8,9], it is shown that the performance of regularized zero forcing and maximum ratio transmission converge in the large dimensional regime and the regularized zero forcing is superior compared with MRT precoding. The large dimensional analysis for receiver design in the BS side was investigated in [10]. The theoretical results of the large dimensional analysis can predict the performance of massive MIMO wireless networks accurately. It is even accurate for some finite cases.

1.1. Contributions

In this paper, we perform network optimization based on the theoretical results of random matrix theory. In previous MIMO network optimization, the power allocation or related capacity optimization relies on the manipulation of instantaneous channel state information [3]. In fast varying network scenarios, such as high speed vehicular networks, the optimization and update should be kept at the same rate with the variations of small scale fading, which is impractical, especially for cellular networks with massive users. The optimization should adapt as fast as the instantaneous CSI. When deploying massive antennas in the BSs side, the SINR of users can be approximated as functions that only depend on the large scale channel statistics. It does not need to follow the variations of instantaneous CSI in the process of network optimization, in this way, much information exchange overhead can be alleviated. Also, it is much more efficient for us to perform optimization over a slow update rate, which requires much less computational cost. This can alleviate much system overhead which is critical for wireless networks. (See Fig. 1).

The main contributions of this paper are summarized as follows:

- We combine the benefits of massive MIMO and user centric cell free networks.
- Large dimensional analysis is carried out to approximate the SINR, which depends only on the channel statistical information.
- We perform optimization based on the channel statistics, which can greatly reduce the system overhead and computational update.

Organizations. The rest of the paper is organized as follows. The system model and sum rate optimization problem is introduced in Section 2. We present the heuristic precoding method that balances signal and interference in Section 3. Then, in Section 4, the large dimensional approximation of certain terms in the SINR and formulation of the power optimization problem that depends only on channel statistics is provided. Numerical results and discussions are presented in Section 5. Section 6 concludes the paper.

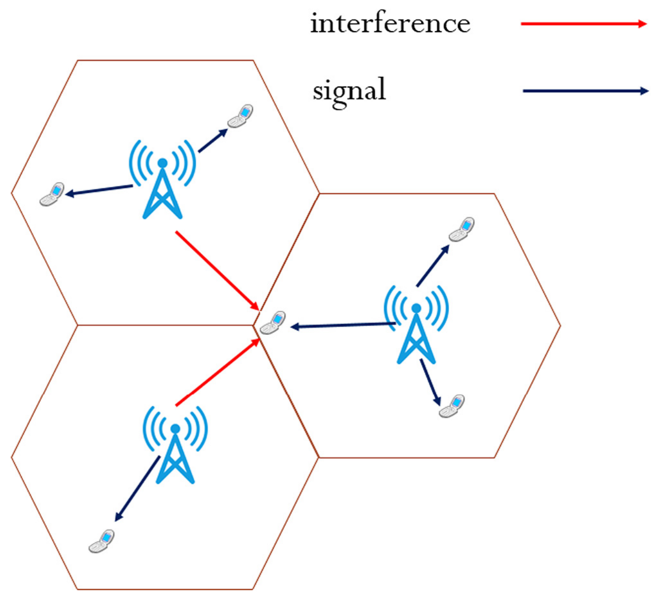

Fig. 1. Traditional cell model.

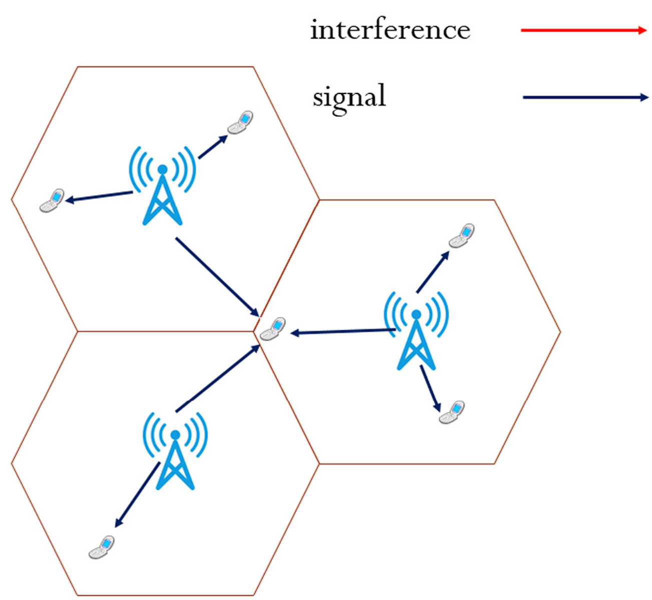

Fig. 2. Cell free model.

2. System model and problem formulation

2.1. Downlink cooperative transmission model

We consider the conventional cellular network which contains K users and M BSs. The network model is given in Fig. 2. We consider the universal frequency reuse in the network transmission. All the BSs operate on the same channels. The interference can be coordinated by efficient precoding. Due to the size limit, each user end is equipped with one antenna, while the BSs are deployed with large number of antennas. N antennas are deployed in each BS. The BSs are connected by backhaul links, which are responsible for information exchange and signal controlling.