

# Iterative Algorithm for Interference Alignment in Cellular Network

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## Abstract

*In this paper, interference alignment is considered for cellular network. Once an equivalent multi-user interference channel is constructed, an iterative algorithm is proposed that finds the precoding and the decoding matrices for the equivalent channel. At each iteration, the proposed algorithm updates the precoding and decoding matrices alternately to minimize the interference leakage. Numerical results are provided that shows the sum rate and the interference leakage as functions of the number of cells and users, respectively.*

**Keywords:** Interference alignment, iterative algorithm, cellular network.

## 1. Introduction

Interference alignment is one of the most promising schemes to achieve the maximum degrees of freedom in an interference channel [1]. In [1], it is shown that the interference alignment achieves  $K/2$  degrees of freedom in the  $K$ -user time-varying and frequency-selective interference channel. The feasibility condition of the interference alignment is also studied in [2].

However, interference alignment requires global channel state information. Moreover, it has no closed-form solution in general. Thus, distributed algorithms that require only local channel state information are proposed to align the interferences of other users into a common subspace [3, 4]. In [3], the precoding and the decoding matrices are alternately chosen to maximize signal to interference plus noise ratio (SINR) by using the reciprocity of the channel. In [4], they are chosen to

minimize the total mean squared error.

In cellular network, the users at cell-edge suffer co-channel interference from neighboring cells. Thus, to improve spectral efficiency of the cell-edge users, interference alignment schemes may be devised to manage the co-channel interference. In [5] and [6], interference alignment schemes are proposed for uplink and downlink cellular networks, respectively. The basic idea is that the precoding and the decoding matrices are designed to align the inter-cell interferences from other cells into a common subspace. However, it is difficult to apply these schemes to the cellular network with more than two cells.

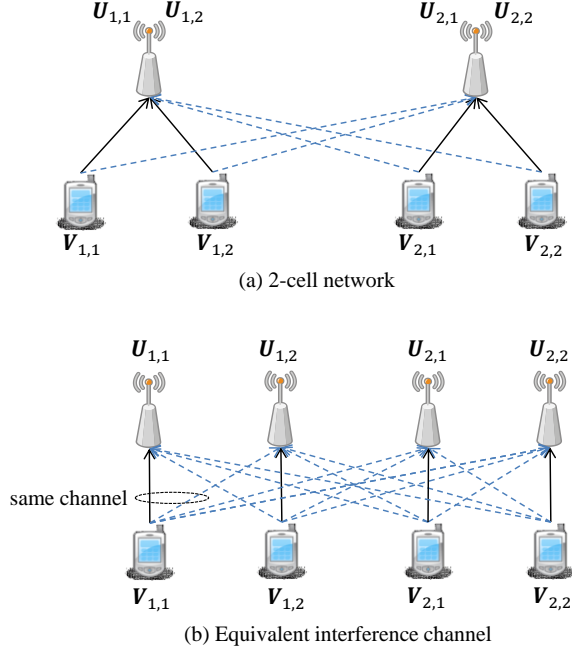
In this paper, we propose an iterative algorithm for interference alignment to minimize the total interference leakage in cellular network. Once an equivalent multi-user interference channel is constructed, the iterative algorithm is proposed that finds the precoding and the decoding matrices for the equivalent channel. At each iteration, the proposed algorithm alternately updates the precoding and the decoding matrices.

The rest of this paper is organized as follows. In Section 2, the system model is given. In Section 3, the iterative algorithm is proposed and numerical results are provided. Finally, concluding remarks are offered in Section 4.

## 2. System model

We consider a cellular system with  $L$  base stations and  $K$  users in each cell. Suppose that each base station (BS) and each user are equipped with  $K$  antennas. Instead of using multiple antennas, either frequency binning or symbol extension can be adopted for interference alignment. We will refer to such a system as  $(L, K)_M^D$  cellular network when each user transmits  $D$  data streams. Fig. 1-(a) shows the system model of the 2-cell network for two users in each cell.

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**Fig. 1. 2-cell network and its equivalent interference channel.**

The cellular network can be equivalently converted into  $KL$ -user interference channel. Unlike general interference channel model, in cellular network, the channels from the  $K$  users in the same cell to BS  $b$  are modeled by the common channel matrix. Let  $\mathbf{H}_{l,k}^b \in \mathbb{C}^{M \times M}$  denote the channel matrix from the user  $k$  in the cell  $l$  to the  $b$ th BS. Fig. 1-(b) shows the 4-user interference channel equivalent to 2-cell network in Fig. 1-(a). Then, the received signal at the  $b$ th BS can be modeled by

$$\mathbf{y}^b = \sum_{l=1}^L \sum_{k=1}^K \mathbf{H}_{l,k}^b \mathbf{V}_{l,k} \mathbf{s}_{l,k} + \mathbf{w}^b$$

where  $\mathbf{V}_{l,k}$ ,  $\mathbf{s}_{l,k}$ , and  $\mathbf{w}^b$  denote the precoding matrix, the data vector of the user  $k$  in the cell  $l$ , and the ambient noise vector of the  $b$ th BS.

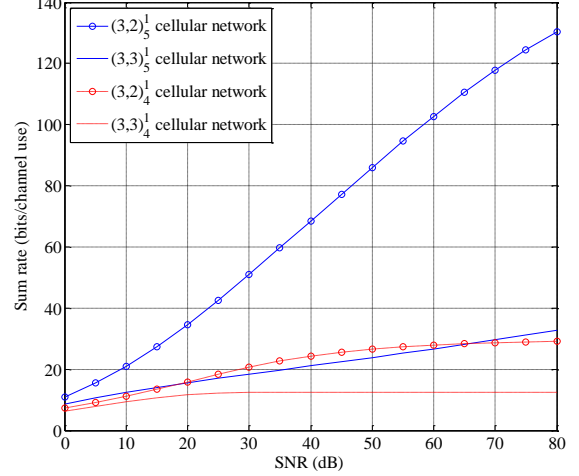
Let  $\mathbf{U}_{b,k}$  denote the decoding matrix of the  $b$ th BS used to decode the data of the user  $k$  in the cell  $b$ . The precoding matrix  $\mathbf{V}_{b,k}$  and the decoding matrix  $\mathbf{U}_{b,k}$  are designed to have independent columns, respectively, i.e.,  $\mathbf{V}_{b,k}^H \mathbf{V}_{b,k} = \mathbf{I}_D$  and  $\mathbf{U}_{b,k}^H \mathbf{U}_{b,k} = \mathbf{I}_D$ .

Then, the SINR matrix of the user  $k$  in the cell  $b$  is given by

$$\mathbf{\Gamma}_{b,k} = (\sigma^2 \mathbf{I}_D + \mathbf{U}_{b,k}^H \mathbf{G}_{b,k} \mathbf{U}_{b,k})^{-1} \mathbf{U}_{b,k}^H \mathbf{S}_{b,k} \mathbf{U}_{b,k}$$

where the signal covariance matrix  $\mathbf{S}_{b,k}$  and the interference plus noise covariance matrix  $\mathbf{G}_{b,k}$  are defined, respectively, as

$$\mathbf{S}_{b,k} \triangleq \mathbf{H}_{b,k}^b \mathbf{V}_{b,k} (\mathbf{H}_{b,k}^b \mathbf{V}_{b,k})^H \quad \text{and}$$



**Fig. 2. Sum rate of proposed algorithm in the cellular network with 3 BS.**

$$\mathbf{G}_{b,k} \triangleq \sum_{l=1}^L \sum_{m=1}^K \mathbf{H}_{l,m}^b \mathbf{V}_{l,m} (\mathbf{H}_{l,m}^b \mathbf{V}_{l,m})^H - \mathbf{S}_{b,k}.$$

Then, the sum rate is given by

$$R_{\text{sum}} = \sum_{b=1}^L \sum_{k=1}^K \log_2 \det(\mathbf{I}_D + \mathbf{\Gamma}_{b,k}).$$

Unlike max-SINR algorithm [7], we proposed a heuristic algorithm to minimize the total interference leakage in next section.

### 3. Iterative algorithm for interference alignment and numerical results

At each iteration, the proposed algorithm alternately updates the precoding matrix  $\mathbf{V}_{b,k}$  and the decoding matrix  $\mathbf{U}_{b,k}$ . The interference leakage  $\epsilon_{b,k}$  of the  $k$ th decoder in the BS  $b$  is given by

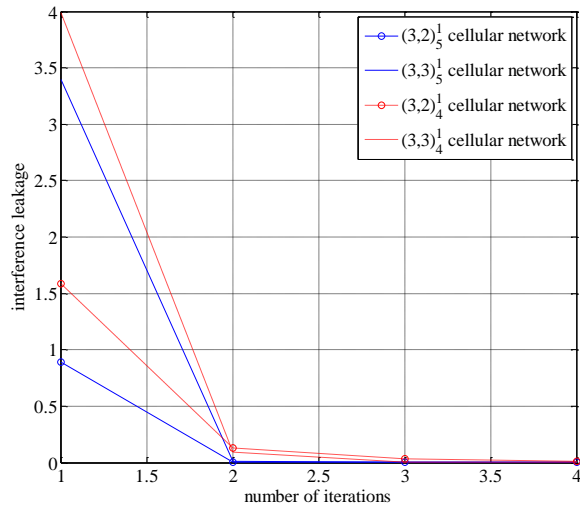
$$\epsilon_{b,k} \triangleq \|\mathbf{U}_{b,k}^H \mathbf{G}_{b,k} \mathbf{U}_{b,k}\|.$$

Then, the total interference leakage is defined as

$$\sum_{b=1}^L \sum_{k=1}^K \epsilon_{b,k}.$$

To minimize the interference leakage  $\epsilon_{b,k}$ , the decoding matrix  $\mathbf{U}_{b,k}$  is updated as  $\mathbf{U}_{b,k} = \mathbf{v}_{\min}^D(\mathbf{G}_{b,k})$ , where  $\mathbf{v}_{\min}^D(\mathbf{A})$  denotes the  $D$  eigenvectors corresponding the  $D$  smallest eigenvalues of  $\mathbf{A}$ . By using the reciprocity of the channel, the precoding matrix is updated as  $\mathbf{V}_{b,k} = \mathbf{v}_{\min}^D(\tilde{\mathbf{G}}_{b,k})$ , where  $\tilde{\mathbf{G}}_{b,k}$  is defined by

$$\tilde{\mathbf{G}}_{b,k} \triangleq \sum_{l=1}^L \sum_{m=1}^K \mathbf{H}_{b,m}^{lH} \mathbf{U}_{l,m} (\mathbf{H}_{b,m}^{lH} \mathbf{U}_{l,m})^H - \mathbf{H}_{b,k}^{bH} \mathbf{U}_{b,k} (\mathbf{H}_{b,k}^{bH} \mathbf{U}_{b,k})^H.$$



**Fig. 3. Interference leakage of proposed algorithm in the cellular network with 3 BS.**

To examine the performance of the proposed algorithm, we consider  $(L, K)_M^D$  with  $L = 3, K = 2, 3$ , and  $M = 4, 5$ . Throughout this section, each user is assumed to transmit a data stream and Monte Carlo simulations are averaged over 100 channels.

Fig. 2 shows the sum rate performance of the cellular networks. It can be seen that the channel interferences are well aligned for  $(3,2)_5^1$ . Fig. 3 shows that the total interference leakage is almost zeros in just 5 iterations.

## 4. Conclusions

In this paper, we propose an iterative algorithm to minimize the total interference leakage for cellular network. At each iteration, the proposed algorithm alternately updates the precoding and the decoding matrices. Numerical results show the sum rate and the interference leakage in various cellular environments.

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