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Research on Downlink Precoding for Interference Cancellation in Massive MIMO Heterogeneous UDN

Hua He, Jing Jiang, Rong Jin

School of Communication and Information Engineering, Xi'an University of Telecommunications and Posts, Xi'an, China
Email: hehua201@xupt.edu.cn

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Abstract

In order to solve the data surge brought by largescale increasing of mobile devices, Massive MIMO ultra dense networking can greatly improve the system spectral efficiency and energy efficiency. It plays an important role in coping with the exponential growth of the business, but also brought big problems and challenges. For heterogeneous ultra dense networks, both macro and femto users are facing with both the cross-layer interference and co-layer interference. The precoding technology studied in this paper resolves the cross-layer interference and co-layer interference for macro users and femto users, and lays a theoretical foundation for the deployment of heterogeneous and ultra dense networks.

Keywords

Ultra Dense Network, Massive MIMO, Heterogeneous, Interference Cancellation

1. Introduction

The development of wireless communication provides great convenience to people's life. With the commercial use of 4 G mobile communication system, the 5 G mobile communication receives more and more attention in academia and industry. The research shows that more than 50% of the voice services and 70% of the data services will be mainly from the indoor terminal in the future. Therefore, UDN (Ultra Dense Network) plays an important role in the future 5 G network, which will become one of the key technologies of 5 G and also become one of the global hot topics [1].

The basic idea of UDN is to enhance the spectral efficiency, the energy efficiency and spectral reuse of the system through reducing the distance between the transmitter and receiver. In UDN, a large number of FBS (Femto Base Station) are generally located in hot spots, such as airports, supermarkets, railway stations and etc, which can greatly increase user data rate [2].

Because of the high density of FBS, the communication coverage between FBSs is often overlapping [3]. The past network-centric clustering algorithm is not practical, while the user-centric clustering algorithm is more applicable, where each FUE (Femto User) can be connected to multiple FBSs. In order to improve the user transmission rate and channel utilization, collaboration between FBS and FUE becomes more critical. But the dense deployment of FBSs will bring severe cross-layer interference and co-layer interference. The interference is expected to be canceled through designing pleasant downlink precoding matrix on transmitter with Massive MIMO, which can enhance the security and the growth of data rate without increasing the transmission power.

The downlink precoding studied in this paper solves the problem of cross-layer interference and co-layer interference of MUEs (macro users) and FUEs in heterogeneous and ultra dense networks, and lays a theoretical foundation for the deployment of heterogeneous and ultra dense networks. The rest of this paper is organized as follows. The second part introduces the heterogeneous UDN system model and user-centric multi connection architecture; the third part introduces the downlink precoding to achieve interference cancellation for MUE; the fourth part introduces the downlink precoding to achieve interference cancellation for FUE.

2. Heterogeneous UDN System Model and Multi Connectivity in User-Centric Architecture

A heterogeneous UDN is described in this paper, which includes a MBS (Macro Base Station) and many FBSs arbitrarily located. All FBSs are within the coverage of the MBS. MBS is responsible for information connection of all FBSs. The transmitting power of MBS is higher and it has larger coverage than FBS; The FBS with low transmitting power can improve indoor coverage and increase network capacity. If Massive MIMO are deployed at MBS and FBS, the system capacity will be increased exponentially. However, due to severe co-layer interference and cross-layer interference, the efficiency of heterogeneous UDN networks will be greatly reduced. **Figure 1** is the network model of heterogeneous UDN.

In **Figure 1**, all FBSs within the MBS coverage are connected to the MBS. The MBS can obtain channel status information of all FBSs and can interact among FBSs. For each FUE, a user-centric clustering strategy with multi connectivity is deployed [4]. The multiple FBSs staying in the FUE coverage are recognized as multiple access points. Because of the limited capability of FBS, each FBS cannot be joined to more FUEs. The FBS should be banned when the number of FUEs joined to the FBS reaches its upper bounder.

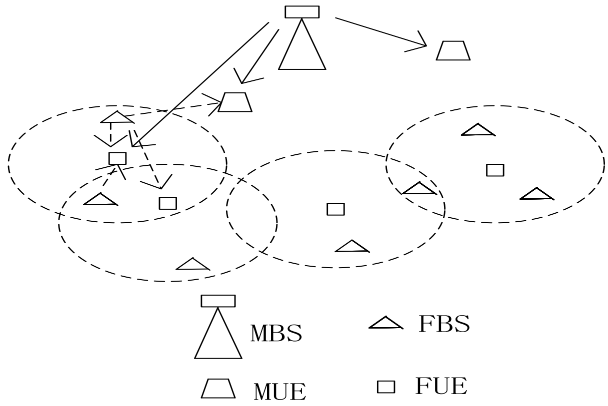

Figure 1. Heterogeneous UDN system model with user-centric architecture.

Due to the high density of FBSs, the interference is severe. Those FBSs not within the user's coverage may still cause interference to the user. Therefore, the ability to cancel interference should be enhanced when user has multi connectivity with the FBSs. Otherwise it is difficult to obtain a higher SINR.

In Figure 1, it is assumed that the number of transmitting antenna of MBS is N_t^M, the number of transmitting antenna of FBS is N_t^F, the number of receiving antanna of MUE and FUE are both N_r. The receiving signal of the k^{th} MUE can be expressed as Equation (1)

$$y_k^M = H_k^M W_k^M X_k^M + \sum_{j\neq k}^{M} H_k^M W_j^M X_j^M + \sum_{F_i=1}^{F_{all}} H_k^{F_i} \sum_{i=1}^{f_i} W_i^F X_i^F + n_k \tag{1}$$

where $H_k^M \in C^{N_r \times N_t^M}$ is the channel metrix from MBS to the k^{th} MUE; $W_k^M \in C^{N_t^M \times l}$ is downlink precoding metrix; $X_k^M \in R^{l\times 1}$ is normalized transmitting signal vector; $H_k^{F_i} \in C^{N^r \times N^t}$ is the channel metrix from FBS to the k^{th} MUE; M is the total number of MUE; F_{all} is the total number of FBS; W_i^F is the precoding metrix of the i^{th} FBS; f_i is the FUE number connecting to the i^{th} FBS; n_k is the noise vector at the kth user, which is an additive Gaussian noise following the distribution CN(0, $\sigma_k^2 I_N$).

Obviously, the interference on k^{th} MUE can be divided into two parts. First part is the multi-user interference within MBS coverage, also called co-layer interference, which is expressed as the second part of the Equation (1); Second part is cross-layer interference on the k^{th} MUE derived from the FBSs, which is expressed as the third part of the Equation (1).

In heterogeneous UDN, the receiving signal of the m^{th} FUE is expressed as Equation (2)

$$y_m^F = \sum_{i=1}^{f_m} H_m^i W_m^i X_m + \sum_{j=1}^{f_n} H_m^j \sum_{n\neq m}^{FU_{all}} W_n^j X_n + \sum_{q=1}^{M} H_k^M W_q^M X_q^M + n_m \tag{2}$$

The interference on the m^{th} FUE obviously consists of two parts seen from Equation (2). First part is the interference from the non-joining FBSs, also called co-layer interference, which is expressed in the second part of Equation (2);

Second is the interference on the MUE from the MBS, also called cross-layer interference, which is expressed as the third part of Equation (2). n_m is the noise vector at the m^{th} FUE, which is an additive Gaussian noise following the distribution CN (0, $\sigma_m^2 I_N$).

From the analysis above, both the MUE and FUE are suffered from the co-layer and cross-layer interference. Thus, designing the pleasant downlink precoding to canceling the two kinds of interference is crucial.

3. Interference Cancellation of the MUE

The cross-layer interference on MUE is considered primarily. The different frequency is allocated to macro cell and femto cell. Generally, The communication frequency between the MBS and the MUE is allocated from 2 G to 6 G. This frequency band has a large communication coverage, and can achieve non-line-of-sight communication. The communication frequency between FBS and FUE is allocated with higher frequency, called millimeter wave communication [5]. The path loss of the millimeter wave communication is serious, the FBS coverage is thus limited. Only the ultra dense deployment of FBS can achieve full coverage. This Frequency division scheme can greatly reduce the cross-layer interference between macro cell and femto cell [6].

Due to the orthogonal resource assignment strategy, cross-layer interference is canceled. And the co-layer interference can be canceled from Equation (1). The receiving signal of the k^{th} MUE can be rewritten as Equation (3)

$$y_k^M = H_k^M W_k^M X_k^M + \sum_{j \neq k}^{M} H_k^M W_j^M X_j^M + n_k \tag{3}$$

The parameters in Equation (3) are referred to Equation (1). For any MUE, only the co-layer interference needs to be canceled.

Still taking the k^{th} MUE for example, the interference channel metrix of the k^{th} MUE can be expressed as below

$$\bar{H}_k^M = \left[\left(H_1^M\right)^H, \left(H_2^M\right)^H \cdots \left(H_{k-1}^M\right)^H, \left(H_{k+1}^M\right)^H \cdots \left(H_M^M\right)^H \right] \tag{4}$$

Generally, the dimension of the MUE's interference channel is relatively small. The block diagonalization method can be used to calculate the downlink precoding of the MBS. Define SVD of $\bar{H}_k^M$ as [7]

$$\bar{H}_k^M = \bar{U}_k^M \begin{bmatrix} \sum_K^{\bar{R}} & 0 \\ 0 & 0 \end{bmatrix} \left(\bar{V}_k^M\right)^H \tag{5}$$

where $\bar{U}_k^M$ and $\bar{V}_k^M$ are both unitary matrix; $\sum_K^{\bar{R}} = diag\left[\lambda_1, \lambda_2 \cdots \lambda_{\bar{R}}\right]$, $\bar{R}$ is the rank of $\bar{H}_k^M$ [8], $\bar{R} \le \min\left[\left(M-1\right) N_t^M, N_r\right]$, λ_i if the non-zero eigenvalue of $\bar{H}_k^M$ [9].

$$\bar{V}_k^M = \left[\bar{V}_k^{M(1)} \bar{V}_k^{M(0)}\right] \tag{6}$$

where $\bar{V}_k^{M(1)}$ are the eigenvectors which corresponds to non-zero eigenvalues; $\bar{V}_k^{M(0)}$ are the eigenvectors which corresponds to zero eigenvalues, and satisfy

$$\bar{H}_k^M \cdot \bar{V}_k^{M(0)} = 0 \tag{7}$$

The downlink precoding of the MBS is

$$W_k^M = \bar{V}_k^{M(0)} \tag{8}$$

4. Interference Cancellation of the FUE

Due to the cross-layer interference cancellation through orthogonal resource assignment between the macro and femto cell, any FUE is also suffered from the co-layer interference. And due to the ultra dense deployment of the FBS, the dimension of the channel is relatively large. The receiving signal of the m^{th} FUE is as follows

$$y_m^F = \sum_{i=1}^{f_m} H_m^i W_m^i X_m + \sum_{j=1}^{f_n} H_m^j \sum_{n=1}^{FU_{all}} W_n^j X_n + n_m \tag{9}$$

Comparing to the Equation (2), the cross-layer interference is canceled in Equation (9). The pleasant downlink precoding needs to be designed to cancel the co-layer interference. The combining channel matrix is denoted as H_m. Let define the pseudo-inverse channel matrix $\tilde{H}_m$ as

$$\tilde{H}_m = H_m^H \left(H_m \cdot H_m^H \right)^{-1} \tag{10}$$

Assumed $\tilde{H}'_m$ is the partial vectors of $\tilde{H}_m$, and satisfies that $\tilde{H}'_m$ is null space of the interference channel matrix $\bar{H}_m$ of the m^{th} FUE. Null space can be achieved through $\tilde{H}_m x = 0$. The non-zero solution of x is null space which can be assigned to $\tilde{H}'_m$. It satisfy

$$\bar{H}_m \cdot \tilde{H}'_m = 0 \tag{11}$$

$$H_m \cdot \tilde{H}'_m = E \tag{12}$$

If $\tilde{H}'_m$ is invertible, $\tilde{H}'_m$ can be made QR decomposition, which is expressed as below [10]

$$\tilde{H}'_m = Q_m \cdot R_m \tag{13}$$

Where Q_m is an orthogonal matrix and R_m is an upper triangular matrix, such that

$$\bar{H}_m \cdot Q_m \cdot R_m = 0 \tag{14}$$

R_m is the invertible upper triangular matrix, such that

$$\bar{H}_m \cdot Q_m = 0 \tag{15}$$

And it satisfies $H_m \cdot Q_m = R_m^{-1}$, such that the receiving FUE needs to add a receiving matrix R_m .The downlink precoding matrix of m^{th} FUE is expressed as Equation (16)

$$W_m = Q_m \tag{16}$$

The upper calculation is based on the invertibility of $\tilde{H}'_m$ [10]. Actually, $\tilde{H}'_m$ is not necessarily invertible. Firstly, $\tilde{H}'_m$ is not necessarily a square matrix; Secondly, even though $\tilde{H}'_m$ is square matrix, but it is not necessarily of full rank. Therefore, before QR decomposition, the invertibility of $\tilde{H}'_m$ has to be ensured.

$\tilde{H}'_m$ selected from null space of $\tilde{H}_m$ must be invertible, such that the vectors of $\tilde{H}'_m$ are irrelevant from each other.

5. Conclusions

Ultra dense network (UDN) can increase the frequency reuse by deploying a large number of low power femto cells, which can greatly improve the spectrum efficiency and energy efficiency. At the same time, there are also many problems and challenges. The cross-layer interference and the co-layer interference in heterogeneous UDN make it difficult to improve the signal to interference noise ratio of the users, which leads to the limited capacity of the system.

Interference can be precanceled at the transmitter by applying massive MIMO downlink precoding technology. This paper studies a heterogeneous network with a user-centric clustering, where FUE have multi connectivity with the FBSs. In this heterogeneous UDN, downlink precoding to cancel co-layer interference is mainly studied. The co-layer interference problem with small dimension is resolved by block diagonalization. The co-layer interference problem with large dimension is resolved based on QR decomposition. The scheme provides a theoretical basis for practical network deployment.

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