Pilot Contamination Reduction in Massive MIMO System

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***Abstract*--This paper proposed two efficient pilot contamination reduction schemes based on the TDD massive MIMO system model: the directional pilot scheme and the multi-cell processing (MCP) scheme. Closed expressions of the user throughput are also derived. According to the simulation results obtained, we can know that the capability of the massive MIMO system can be significantly improved and the robustness is also achieved through the proposed scheme. Due to a lack of good strategies for pilot contamination reduction, the proposed schemes in this paper provide some new solutions for this problem with strong innovation.**

***Index Terms*--Massive MIMO, Pilot contamination, Directional antennas, Multi-cell processing**

I. INTRODUCTION

In the Massive MIMO system, the reason for the cause of pilot contamination is non-orthogonal training sequences [1]. Non-orthogonal training sequences have a greater effect on the channel estimate and the worsened precoding matrices cause severe inter-cell interference. Ultimately, with the increasing of the number of base station antennas, the throughput of the system cannot grow. It is confined to a small value. [2] develops a modified frame structure in each cell. At non-overlapping times in each cell, the pilot transmission is completed. [3] analyzes the basic issue of pilot contamination existing in multi-cell systems. What' more [3] proposes a new precoding method which is based on multi-cell MMSE to mitigate pilot contamination. The above two articles discussed pilot contamination reduction from the perspective of modifying protocol. Research on pilot contamination needs to go further, this paper studies the pilot contamination reduction schemes from the perspective of multi-antenna configuration at the terminal and multi-cell processing. The proposed schemes in this paper provide new solutions for this problem with strong innovation.

II. SYSTEM MODEL

We assume a cellular system. In the system, there are L cells. Every cell contains one base station, and the base station has K single-antenna users and M antennas. We assume that the channels of the forward and reverse links are reciprocal [4], and base stations use uplink pilots to estimate channels and further to form precoding matrices. There are L base stations sharing the same frequency band. Meanwhile, these base stations also share the same set of K orthogonal pilot signals. For the base station, it has an average power of ρ_f during transmission. What's more, during the transmission the average power at each user is ρ_r. The propagation factor between the *m-th* base station antenna of the *l-th* cell and the *k-th* user of the *j-th* cell is $\sqrt{\beta_{jlk}}h_{jlkm}$.

III. PILOT CONTAMINATION ANALYISI AND OPTIMIZAITON SCHEMES

A. Directional Pilot Scheme

The pilot signals can be transmitted directionally when terminals are equipped with multiple antennas. In order to simplify the discussion, two cells of which consists of one base station with M antennas and one single-antenna user are considered, $-90^\circ \le \varphi_1$、$\varphi_2 \le 90^\circ$ denote the azimuth angle, as shown in Fig 1. The directional pilot scheme consists of four phases: aimless search, azimuth feedback, directional feedback, transmit symbols, as shown in Fig. 2. The gain of the main lobe compensates the large scale fading of the local cell while the gain of side lobe enhances the large scale fading from local cell to other cells.

$$\tilde{\beta}_{jj} = g\beta_{jj}, \tilde{\beta}_{jl} = g_\varphi \beta_{jl} \tag{1}$$

where g is the gain of the main lobe, g_φ is the gain of azimuth φ .This directional pilot scheme can realizes pilot contamination reduction by utilizing the spatial characteristic of multiple antennas equipped at the terminal.

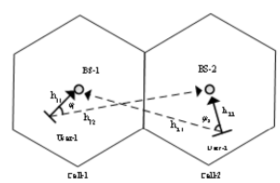

Fig.1 Two cells of whichcontains one base station with one single-antenna user and M antennas, each userdeploy N santennas.

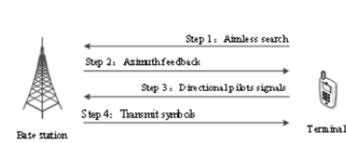

Fig.2 Directional pilot scheme

Suppose terminal antennas are not relevant, the link capacity is positively correlated with the number of antennas of the terminal. The maximum achievable information rate of each antenna at the terminal can be expressed as[3]

$$R_j = C\left(\frac{\rho_f \tilde{\beta}_{jj} \dfrac{\rho_r \tau \tilde{\beta}_{jj}}{1+\rho_r \tau \sum_{i=1}^{L} \tilde{\beta}_{ij}} E^2[\theta]}{\sum_{l \ne j} \rho_f \tilde{\beta}_{jl} \dfrac{\rho_r \tau \beta_{jl}}{1+\rho_r \tau \sum_{i=1}^{L} \tilde{\beta}_{ij}} E[\theta^2] + \varsigma}\right) \tag{2}$$

where $\varsigma = 1 + \rho_f \beta_{jj} \dfrac{\rho_r \tau \tilde{\beta}_{jj}}{1+\rho_r \tau \sum_{i=1}^{L} \tilde{\beta}_{ij}} \mathrm{var}[\theta] + \sum_{l=1}^{L} \rho_f \tilde{\beta}_{jl} \dfrac{1+\rho_r \tau \sum_{i \ne j}^{L} \tilde{\beta}_{il}}{1+\rho_r \tau \sum_{i=1}^{L} \tilde{\beta}_{il}}$, θ obeys the Chi-square distribution, $E[\theta]=\frac{\Gamma(M+1/2)}{\Gamma(M)}$, $E[\theta^2]=M$, where $\Gamma(.)$ is the Gamma function.

B. Multi-cell processing scheme

This section mainly studies the impact of multi-cell processing on pilot contamination. MCP means BSs know the channels from all BSs to all the mobiles in the whole network, as well as the data to be transmitted .We assume *i-th* cell and *j-th* cell cooperate with each other fully and others are non-cooperate, the received signal of user in j-th cell is

$$x_j=\sqrt{\rho_f}(\sqrt{\beta_{jj}}h_{jj}a_{jj}q_j+\sqrt{\beta_{jl}}h_{jl}a_{jl}q_j)+\sqrt{\rho_f}(\sqrt{\beta_{jj}}h_{jj}a_{lj}q_l +\sqrt{\beta_{jl}}h_{jl}a_{ll}q_l)+\sum_{v=1,v\neq j,v\neq l}^{L}\sqrt{\rho_f}\sqrt{\beta_{jv}}h_{jv}a_{jv}q_v+z_j \quad (3)$$

where h_{jl} and β_{jl} denote small scale fading coefficients and large scale fading coefficients from user j to base station l respectively. a_{jl} denotes the precoding matrix of the *l-th* base station to *j-th* user, q_j is the data required by *j-th* user, z_j is the additive noise.

In order to simplify the discussion, we assume $L=2$. In the *j-th* cell, the downlink achievable rate of the user is derived as

$$R_j=C(\frac{\varsigma}{1+\chi+\varepsilon}) \quad (4)$$

where $\varsigma=\frac{\rho_f\rho_r\tau}{1+\rho_r\tau(\beta_{jj}+\beta_{lj})}\beta_{jj}^2E^2[\eta]+\frac{\rho_f\rho_r\tau}{1+\rho_r\tau(\beta_{jl}+\beta_{ll})}\beta_{jl}^2E^2[\eta] +\frac{2\cdot\rho_f\rho_r\tau\beta_{jj}\beta_{jl}E^2[\eta]}{\sqrt{1+\rho_r\tau(\beta_{jl}+\beta_{ll})}\sqrt{1+\rho_r\tau(\beta_{lj}+\beta_{ll})}}$, $\chi=(\frac{\rho_f\rho_r\tau\beta_{jj}^2}{1+\rho_r\tau(\beta_{jj}+\beta_{lj})} +\frac{\rho_f\rho_r\tau\beta_{jl}^2}{1+\rho_r\tau(\beta_{jl}+\beta_{ll})})\mathrm{var}[\eta]+\frac{\rho_f\beta_{jj}(1+\rho_r\tau\beta_{lj})}{1+\rho_r\tau(\beta_{jj}+\beta_{lj})}+\frac{\rho_f\beta_{jl}(1+\rho_r\tau\beta_{ll})}{1+\rho_r\tau(\beta_{jl}+\beta_{ll})}$, $\varepsilon=\rho_f\beta_{jj}\frac{1+\rho_r\tau(\beta_{jj}+\beta_{lj})}{\rho_r\tau\beta_{lj}E[\eta^2]}E[\left\|h_{jj}\hat{h}_{lj}^H\right\|^2]+\rho_f\beta_{jl}\cdot\frac{1}{\rho_r\tau\beta_{ll}E[\eta^2]}\cdot (1+\rho_r\tau(\beta_{jl}+\beta_{ll}))E[\left\|h_{jl}\hat{h}_{ll}^H\right\|^2]$,where η obeys the Chi-square distribution, $E[\eta]=\frac{\Gamma(M+1/2)}{\Gamma(M)}$, $\mathrm{var}[\eta]=M-E^2[\eta]$, $E[\eta^2]=M$.

IV. PERFORM ANCE RESULTS

We consider a system that consists of two cells. In these two cell, there is $\rho_f=10dB$, $\rho_r=0dB$ and $K=1$ user. What's more, we set the bandwidth is 20MHz and the direct gains $\beta_{jj}=1$ and cross gains $\beta_{jk}=a(a<1)$. In Fig.3, we plot the performance of no pilot contamination, directional pilot scheme, omnidirectional pilot scheme and shifted pilots scheme[1] for different values of a when $M=64, N=4, L=2, T=7, \tau=3, \varphi_2=20^{\circ}$. We observe significant advantage of using directional pilot scheme. When compared with shifted pilots scheme, the proposed scheme performs better when a is no big enough. In addition, the shifted pilots scheme works bad with no ideal time synchronization, but the proposed scheme has good robustness. This directional pilot scheme can realize pilot contamination reduction by utilizing the spatial characteristic of multiple antennas equipped at the terminal and it is fit for the future mobile communication system.

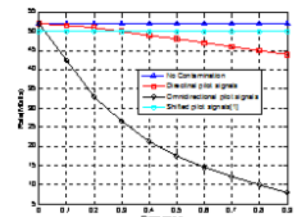

Fig.3. Performance comparison of no pilot contamination, directional pilot scheme, omnidirectional pilot scheme and shifted pilots scheme [1] for different values of α when M=64, N=4, T=7, τ=3

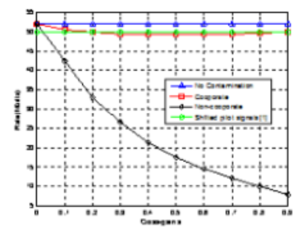

Fig.4. Performance comparison of no pilot contamination, non-cooperate scheme, MCP scheme and shifted pilots scheme [1].

In Fig. 4, we plot the performance of no pilot contamination, non-cooperate scheme, MCP scheme and shifted pilots scheme [1]. We observe that non-cooperate scheme and MCP scheme have similar properties when a is very small, which agree with the facts. With the value of a on the rise, the non-cooperate scheme works so bad and the MCP scheme has stable performance. But the MCP scheme and the shifted pilots scheme perform well only on the condition of ideal time synchronization.

V. CONSLUSION

This paper proposed two efficient pilot contamination reduction schemes based on the TDD massive MIMO system model: the directional pilot scheme and the MCP scheme. Closed expressions of the user throughput are also derived. According to the simulation results obtained, we can know that the capability of the massive MIMO system can be significantly improved and the robustness is also achieved through the proposed scheme. Due to a lack of good strategies for pilot contamination reduction, the proposed schemes in this paper provide some new solutions for this problem with strong innovation.

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