

Suppressed Inter-cell Asynchronous Interference By Delay-tolerance SLNR Precoding

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Abstract--- The different propagation times due to the distinct distance between the BSs and MSs result in inter-cell asynchronous interference, which severely destroy system performance. How to mitigate inter-cell asynchronous interference by making use of SLNR precoding is the key to this paper. Firstly, a framework of Cooperative Base Station Systems (Co-BS) was developed and the delay between the cells was analysed. Secondly, a delay-tolerance SLNR precoding was brought forward, in LTE system which exist delay, to suppress inter-cell asynchronous interference. And this method can also reduce the complication of terminal. Finally, the numerical delay-tolerance SLNR precoding simulation results are presented based on Cooperative Base Station LTE Systems, the conclusions show that it can mitigate inter-cell asynchronous interference. And the method can reach a good performance under different antenna configuration, which make performance progress compare with receive algorithm. Besides, the performance is affected by channel estimation error, but it can still be accepted.

Keywords—MIMO; Co-BS; Precoding; SLNR; Asynchronous interference

I. INTRODUCTION

High-speed large-capacity data service has become significant for future mobile communication systems, LTE, Wimax and IMT-Advance all adopt MIMO as a key technology to gain system throughput. This is because the spectral efficiency gained and system capacity can largely improved in MIMO system of wireless channel without increasing the bandwidth of communications. With the further standardized of next generation specification of mobile communications, multi-cell structure that based on MIMO technology has begun to attract increasing attention, multi-cell system can remarkably enhance spectral efficiency of cellular systems and boost system throughput. Since, different BSs' antennas can be coordinated communications to augment system throughput and achieve high-speed transmission, base station Collaboration System (Co-BS)^{[1] [2]} was proposed, it also called super eNB^[4], network MIMO,

Co-MIMO, Co-MP. [5] [6] have proved that Co-BS systems can significantly improve the spectrum efficiency, as well as effectively suppress the adjacent cell interference between users.

It has been noticed that there is RNC (radio network controller) in GSM, WCDMA system, which ensure carrying out centralized scheduling to realize cooperative BSs, and make sure of smaller propagation delay. However, in LTE system and the future system of IMT-Advance, they do not have RNC to coordinate inter-cell transmission, which result in larger propagation delay. Even if the desired signals can arrive at their intended user at the same time, the BSs cannot also align all the interference signals simultaneously arrive at each user because of the different propagation times between the BSs and MSs, resulting in inter-cell asynchronous interference.

There are two ways to get rid of co-channel interference (CCI) of Co-BS system which introduce MIMO technology, one is from receiver^{[7][8]} while another one is from transmitter. Precoding is one manner of Co-BS multi-antenna configuration which considering problem from transmitter side, by introducing precoding^[9] to transmitter, each eNB signals can be reconstructed to accommodate varies channel environment. [10][11][12] utilized precoding method to deploy joint optimization to reduce negative impact bring from delay. However, mutli-cell joint optimization with quite heavy complexity, it is hard to achieve in practical applications. Therefore, we considering of cooperation between base stations to obtain its and adjacent-cell's channel information and asynchronous information also sharing them, then each base station carry out respectively precoding on the foundation of previous information, as a result it not only inhibit inter-cell asynchronous interference, but also makes terminal easier to receive and detect signal, greatly lower terminal complexity corresponding, and avoid the huge difficulties of joint optimization.

This paper discusses how to mitigate inter-cell asynchronous interference by making use of SLNR precoding. Develop a interference suppression scheme in allusion to inter-cell interference of LTE multi-cell cooperative system, especially

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when the different propagation times due to the distinct distance between the BSs and MSs. Firstly, this paper give a framework of Cooperative Base Station Systems (Co-BS) and analyse the delay between the cell. Secondly, design a delay-tolerance SLNR precoding based on SLNR rule, in LTE system which exist delay, to suppress inter-cell asynchronous interference, and this method can also reduce the complication of terminal. Finally, the numerical delay-tolerance SLNR precoding simulation results are presented, the simulations are based on LTE Cooperative Base Station Systems, the conclusions show provoking scheme can mitigate inter-cell asynchronous interference. And the method can reach a good performance under different antenna configuration, which make performance progress compare with receive algorithm. Besides, the performance is affected by channel estimation error, but it can still be accepted.

II. SYSTEM MODEL

We consider a system model as figure 1, the system with B BSs (each with N_T antennas) and K MSs/Users (each with N_R antennas).

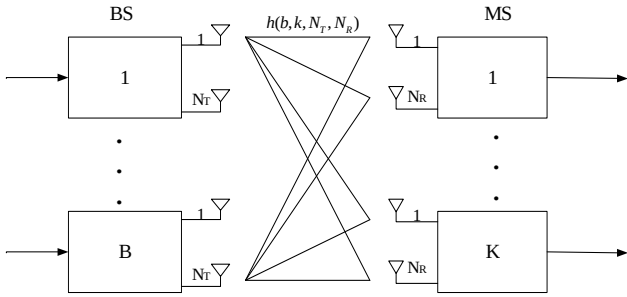


Figure 1. System model of Co-BS

The cooperative BSs together transmit $L_k \times 1$ data streams to MS k at time m denoted by $s_k(m)$. The transmit vector for MS k from BS b is linearly precoded by matrix T_k^b (of size $N_T \times L_k$) as $x_k^b = T_k^b s_k$, According to different system design, T_k^b takes on different function (such as power allocation, antenna selection or beam-forming, interference mitigation and so on), in this paper it acts as the function of interference mitigation.

Matrix H_k^b represents the channel from BS b to MS k , has complex Gaussian elements. H_k is the channel between all cooperative BSs and MS k , while H_j is the channel between all cooperative BSs and MS j (which is the source of the interference).

When the asynchronous is neglected, that is the system's desired signal and interference are completely synchronous. The receiver signal at time t of MS k as following:

$$y_k(m) = \sum_{b=1}^B H_k^b T_k^b s_k(m) + \sum_{j=1, j \neq k}^K \sum_{b=1}^B H_k^b T_j^b s_j(m) + n_k(m) \quad (1)$$

$$= H_k T_k s_k(m) + \sum_{j=1, j \neq k}^K H_k T_j s_j(m) + n_k(m)$$

Where, $H_k = [H_k^1, H_k^2, \dots, H_k^B]$, $T_k = [T_k^{1H}, T_k^{2H}, \dots, T_k^{BH}]^H$.

The first term denotes the desired signal from BSs to MS k at time m , the second term denotes the interference at MS k from the signal transmitted by BSs for MS j ($j \neq k$), $n_k(m)$ is the additive white Gaussian noise vector with the zero-mean and σ^2 -variance. Besides, the signal has the following property in synchronous system:

$$E[s_k(m)s_k(m)^H] = I_{L_k} \quad (2)$$

$$E[s_k(m)s_j(m)^H] = 0 \quad \text{for } k \neq j$$

Conventional interference mitigation methods are utilizing MDU at receiver. Such as linear receiver with linear processing of the received signal, estimate transmit signal via multiplying a linear transformation matrix G_k to received signal:

$\hat{y}_k = G_k y_k$. Linear MMSE receiver is the most popular linear receiver, precoding matrix can be considered as unit matrix when adopting detection scheme, and get the expression for G_k :

$$G_k = H_k^H \left[H_k H_k^H + \sum_{j=1, j \neq k}^K H_k H_k^H + N_R I \right]^{-1} \quad (3)$$

III. DELAY-TOLERANCE SLNR PRECODING

A. Analysis of Inter-cell Asynchronous Interference

There is RNC (radio network controller) in GSM, WCDMA system, which ensure carrying out centralized scheduling to realize cooperative BSs, and make sure of smaller propagation delay. However, in the LTE system and the future system of IMT-Advance, they do not have RNC to coordinate inter-cell transmission that result in larger propagation delay. Even if the desired signals can reach their intended user at the same time, the BSs cannot also align all the interference signals simultaneous arrival at each user because of the different propagation times between the BSs and MSs, resulting in inter-cell asynchronous interference. Fig2 gives a delay model ^{[11] [12]}.

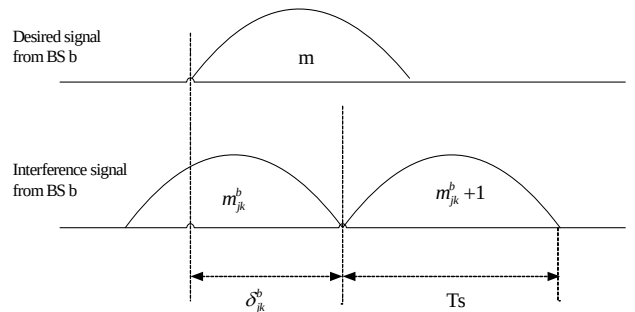


Figure 2. Symbol delay illustration

Let τ_k^b denotes the propagation delay from BS b to MS k . When system exist delay, to guarantee accurately simultaneous reception of desired signal, BS needed to identify a benchmark time, and adopt timing-advances(for positive advance, otherwise delay) to adjusts the transmit time by $\Delta\tau_k^b = \tau_k^b - \tau_k^{b_k}$, so that desired signal of all BSs to user k have an uniform delay $\tau_k^{b_k}$.

At MS k , the received signal at time t is passed through a matched filter $g(t - mT_s - \tau_k^{b_k})$ which is also delayed by $\tau_k^{b_k}$ to ensure the synchronized of desired signals. However, interference signals from other users cannot arrive at the same time for the BS's different adjusting times between MS_k and MS_j . i_{jk}^b is asynchronous interference at MS_k from the signal transmitted by BS b for MS_j , τ_{jk}^b represents the difference timing-advances between them, and $\tau_{jk}^b = (\tau_k^b - \Delta\tau_j^b) - \tau_k^{b_k} = \Delta\tau_k^b - \Delta\tau_j^b$.

The asynchronous interference i_{jk}^b arises from two consecutive symbols with indices m_{jk}^b and $m_{jk}^b + 1$, that are transmitted to MS_j from BS b . Let $\delta_{jk}^b = \tau_{jk}^b \bmod T_s$. Then,

$$i_{jk}^b(m) = \rho(\delta_{jk}^b - T_s) s_j(m_{jk}^b) + \rho(\delta_{jk}^b) s_j(m_{jk}^b + 1) \quad (4)$$

where, $\rho(\tau) = \int_0^{T_s} g(t)g(t - \tau)dt$, with $\rho(0) = 1$.

To simplify the analysis, we suppose that each base station to MS_j 's delay is consistent, that is, MS_j 's date sent from each base station have a common delay relative to MS_k , then δ_{jk}^b can be abbreviated as δ_{jk} , $i_{jk}^b(m)$ can be abbreviated as $i_{jk}(m)$ corresponding, and $i_{jk}(m) = \rho(\delta_{jk} - T_s) s_j(m_{jk}) + \rho(\delta_{jk}) s_j(m_{jk} + 1)$.

To sum up, interference item should be revised when there is delay in equation (1), receiver signal of Co-BS systems changed as:

$$y_k(m) = H_k T_k s_k(m) + \sum_{j=1, j \neq k}^K H_j T_j i_{jk}(m) + n_k(m) \quad (5)$$

B. Delay-tolerance SLNR Precoding

Equation (5) consider the interference at desired user that caused by other users, now we consider the interference caused by the desired user on other users, that is leakage^[13]. The leakage for users k can be written as L :

$$L = \sum_{j=1, j \neq k}^K H_j T_k i_{kj}(m) \quad (6)$$

Combined desired signal, leakage and noise all together like this:

$$y_{kl}(m) = H_k T_k s_k(m) + \sum_{j=1, j \neq k}^K H_j T_j i_{kj}(m) + n_k(m) \quad (7)$$

When the asynchronous of interference is neglected, or when interference signals and desired signal are supposed to synchronous, expression (7) degrade to:

$$y_{kl}(m) = H_k T_k s_k(m) + \sum_{j=1, j \neq k}^K H_j T_k s_k(m) + v_k(m) \quad (8)$$

If system is asynchronous, using SLNR toward expression (7) to measure system performance. The delay-tolerance SLNR precoding of user k is defined as below $S_{SLNR_{k_delay}}$:

$$S_{SLNR_{k_delay}} = \frac{\|H_k T_k s_k(m)\|^2}{N_R \|n_k(m)\|^2 + \left\| \sum_{j=1, j \neq k}^K H_j T_j i_{kj}(m) \right\|^2} \quad (9)$$

As in synchronous system, desired signal and leakage item in equation (8) are both contain $s_k(m)$ which with the characteristic of expression (2), using SLNR toward expression (8) then it can be directly simplified and Rayleigh quotient can be introduced to solve problem. However, when the system holds delay, desired signal item doesn't keep the same as leakage signal item, thus the advanced method cannot straight adopted, some transformation are needed.

Let $I_{kj}(m) = \sum_{j=1, j \neq k}^K H_j T_k i_{kj}(m)$, first of all, we analyse

the property of $i_{kj}(m)$ in leakage item:

$$E[i_{kj_1}(m) i_{kj_2}(m)^H] = 0 \quad \begin{matrix} j_1 \neq j_2 \neq k \\ \forall j_1, j_2, k \in \{1, 2, \dots, K\} \end{matrix} \quad (10)$$

$$E[i_{kj}(m) i_{kj}(m)^H] = \begin{cases} \rho^2(\delta_{kj}) + \rho^2(\delta_{kj} - T_s) I_{L_k}, & j \neq k \\ I_{L_k}, & j = k \end{cases} \quad (11)$$

Here, define delay interference correlation coefficient γ_{kj} as:

$$\gamma_{kj} = \begin{cases} \rho^2(\delta_{kj}) + \rho^2(\delta_{kj} - T_s), & j \neq k \\ 1, & j = k \end{cases} \quad (12)$$

Making the writing transform of γ_{kj} like this:

$$\begin{aligned} \gamma_k &= \gamma_{kk} = 1 \\ \tilde{\gamma}_k &= [\gamma_{k1}, \dots, \gamma_{k(k-1)}, \gamma_{k(k+1)}, \dots, \gamma_{kK}] \end{aligned} \quad (13)$$

$$\begin{aligned}
S_{SLNR_{k_delay}} &= \frac{\|H_k T_k s_k(m)\|^2}{N_R \|n_k(m)\|^2 + \left\| \sum_{j=1, j \neq k}^K H_j T_k i_{kj}(m) \right\|^2} \\
&= \frac{\|H_k T_k\|^2}{N_R \sigma^2 + \sum_{j=1, j \neq k}^K \gamma_{kj} \|H_j T_k\|^2}
\end{aligned} \quad (14)$$

By maximizing $S_{SLNR_{k_delay}}$, and using Rayleigh quotient to solve problem, can work out delay-tolerance SLNR precoding matrix T_k of user k as follow:

$$\begin{aligned}
T_k &= \arg \max_{T_k \in \mathbb{C}^{N_T \times L_k}} S_{SLNR_{k_delay}} \\
&= \max \text{generalized eigenvector}(H_k^H H_k, N_R \sigma^2 I + \sum_{j=1, j \neq k}^K \gamma_{kj} \times H_j^H H_j) \\
&= \max \text{eigenvector}((N_R \sigma^2 I + \tilde{\gamma}_k \cdot (\tilde{H}_k^H \tilde{H}_k))^{-1} H_k^H H_k)
\end{aligned} \quad (15)$$

Where, $\tilde{H}_k$ denote the leakage space of user k , $\tilde{H}_k = [H_1, \dots, H_{k-1}, H_{k+1}, \dots, H_K]$, it is the null space(or nuclear space) for H_k . $\cdot$ represents multiplexing γ_{kj} and $H_j^H H_j$, $\tilde{\gamma}_k \cdot (\tilde{H}_k^H \tilde{H}_k) = \sum_{j=1, j \neq k}^K \gamma_{kj} \times H_j^H H_j$. By doing so, and finding the maximum eigenvector of matrix $((N_R \sigma^2 I + \tilde{\gamma}_k \cdot (\tilde{H}_k^H \tilde{H}_k))^{-1} H_k^H H_k)$, delay-tolerance SLNR precoding matrix T_k can be worked out.

IV. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

According to the simulation result of paper [14], majority interference signal the receiver suffered comes from the most neighbouring 2 or 3 cells among all interference. So that both transmitter and receiver can focus on dealing strongly interference, and effectively reduce the complexity of interference mitigation as well. The simulation of this paper is based on LTE cooperative system with 3 cells, and each cell contains one user. Without loss of generality, we examine the performance of user 1. LTE system parameters refer to [15]: we use QPSK modulation and spatial multiplexing, PRB number is 25, bandwidth $B = 5\text{MHz}$, carrier frequency $f_c = 2\text{GHz}$, slot length is 0.5ms, each slot contains 7 OFDM symbols, each OFDM lasts $71.43\mu\text{s}$, CP type is short CP, IFFT / FFT length is 512. In the simulation, in order to highlight the performance of provoking method we do not adopt channel coding for simplify, all path between transmit antenna and receive antenna are undergo frequency-flat Rayleigh fading channel, and channel elements are independent and are complex Gaussian distribution with zero-mean and unit-variance.

A. Basic Performance of Delay-tolerance SLNR Precoding

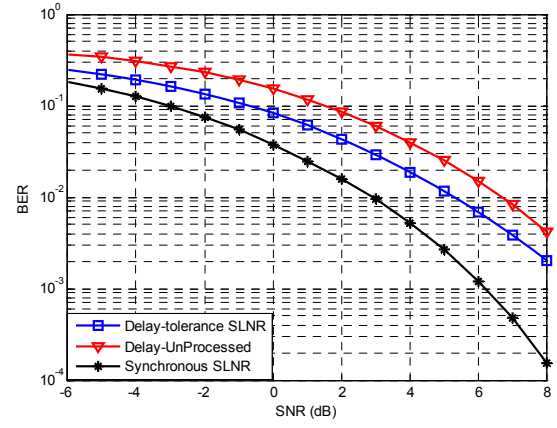


Figure 3. The basic performance of delay-tolerance SLNR precoding

Finger 3 illustrate basic feature for delay-tolerance SLNR precoding in cooperative system which consists of 2 transmit antennas and 2 receive antennas. Black curve describes the performance for SLNR precoding under the situation of system are totally synchronized, then compares precoding when it takes the asynchronicity of the interference into account (delay-tolerance SLNR, blue curve) and when it incorrectly ignores asynchronicity despite it being present (red curve). As can be seen from the figure when there is delay in interference, but was ignored and failed to take appropriate measurement to overcome it, system performance deteriorated sharply since the LTE system impose OFDM technology which has high demand of synchronization. Terminal feedback captured precision delay information and channel information to transmitter which with precoding scheme, transmitter utilize the information in precoding period to realize delay-tolerance SLNR precoding to improve system performance. The provoking precoding method mitigates asynchronous interference to some extent and enhances system capability. However, the situation is still serious compare to synchronous circumstances, further analysis and corresponding precoding are necessary.

B. The Comparative of Delay-tolerance SLNR Precoding and Detective Algorithm

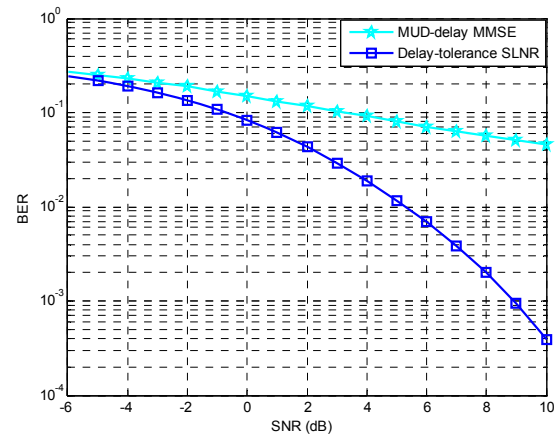


Figure 4. The comparative of delay-tolerance SLNR precoding and MMSE detective algorithm

Figure 4 compares delay-tolerance SLNR precoding and conventional MMSE detective algorithm in the existence of asynchronous interference scenario, in which the number of BS antenna and MS antenna respectively for 2-2 configuration. As can be illustrated, delay-tolerance SLNR precoding outperform MMSE detective plan, mainly because only two receiving antennas, there is no residual degrees of freedom to deal with interference after dealing with desired signal. This shows that proactive interference suppression scheme at transmitter for cooperative system is superiority especially under high signal-to-noise ratio.

C. Performance on Different Antenna Configuration

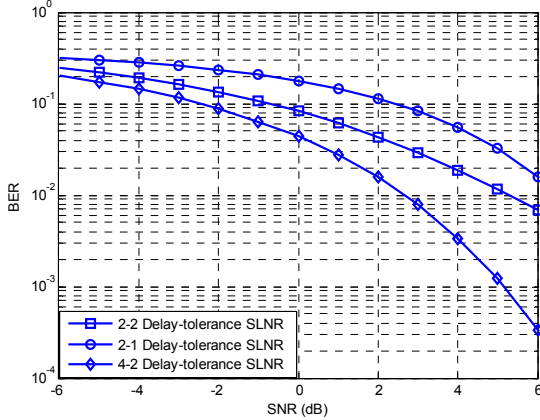


Figure 5. Delay-tolerance SLNR precoding performance on different antenna configuration

Figure 5 compare delay-tolerance SLNR precoding performance in different antenna configuration system. The number of users and transmit antennas are 2-1, 2-2, 4-2. Simulation results show that the more transmit antennas the better system performance, because the more antennas configuration the better diversity. So the algorithm is especially effective in multi-antenna systems.

D. The Impact of Imperfect Channel State Information

The precoding can reduce the complexity of mobile station, but the premise is that the BS knows the perfect channel state information. Frontal simulations are on the assumption that estimated channel is perfect channel state information. However, in the real communication, the channel state information is usually imperfect. So we will research the effect of imperfect channel state information to delay-tolerance SLNR precoding performance.

It is assumed that $h(t)$ is a complex Gaussian variable with zero-mean and unit-variance. Its autocorrelation function is $J_0(2\pi f_d T_d)$, where f_d is the maximal Doppler frequency shift, T_d is the time-delay, $J_0(x)$ is the zero-order Bessel function. Because $h(t)$ is complex Gaussian variable, $h(t) - h(t - T_d)$ is complex Gaussian variable too, its variance is:

$$\sigma_h^2(T_d) = E|h(t) - h(t - T_d)|^2 = 2[1 - J_0(2\pi f_d T_d)] \quad (16)$$

So the channel model with time-delay will be denoted as

$$h(t) = \hat{h}(t) + \sigma_h(T_d)n(t) \quad (17)$$

Where, $h(t)$ is real-time channel response, $\hat{h}(t)$ is the estimated channel, $n(t)$ is a complex Gaussian variable with zero-mean and unit-variance. With dispersing processing, channel matrix can be expressed as bellow:

$$\mathbf{H}_k = \hat{\mathbf{H}}_k + \mathbf{e}_k \quad (18)$$

Here $\mathbf{H}_k$ is real-time channel matrix, $\hat{\mathbf{H}}_k$ is the estimated channel matrix, $\mathbf{e}_k$ is channel-error matrix, its elements are complex Gaussian variable with zero-mean and $\sigma_h^2(T_d)$ - variance. Therefore, delay-tolerance SLNR precoding of user k in imperfect channel state information now is:

$$\begin{aligned} \mathbf{T}_k &= \max \text{ eigenvector} \\ &= \left(\left(\mathbf{N}_R \sigma^2 \mathbf{I} + \sum_{j=1, j \neq k}^K \gamma_{kj} (\hat{\mathbf{H}}_k + \mathbf{e}_k)^H (\hat{\mathbf{H}}_j + \mathbf{e}_j) \right) (\hat{\mathbf{H}}_k + \mathbf{e}_k)^H (\hat{\mathbf{H}}_k + \mathbf{e}_k) \right)^{-1} \\ &= \left((\mathbf{N}_R \sigma^2 \mathbf{I} + \tilde{\gamma}_k^* ((\hat{\mathbf{H}}_k + \mathbf{e}_k)^H (\hat{\mathbf{H}}_k + \mathbf{e}_k)))^{-1} (\hat{\mathbf{H}}_k + \mathbf{e}_k)^H (\hat{\mathbf{H}}_k + \mathbf{e}_k) \right) \end{aligned} \quad (19)$$

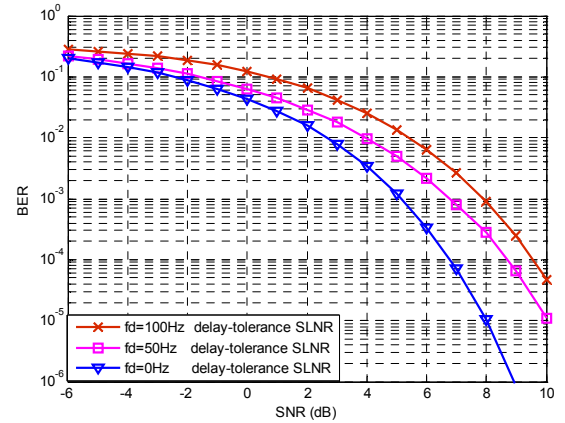


Figure 6. Channel estimation error effect on delay-tolerance SLNR precoding performance

Figure 6 illustrates the performance of delay-tolerance SLNR precoding with imperfect channel state information, antenna configuration is 2-2. Figs indicate the performance with various Doppler frequency shift (0Hz, 50Hz, 100Hz) where the feedback-delay is 1.5ms, it shows performance turns out to be bad as feedback-delay increasing.

V. CONCLUSION

In this paper, we investigated the inter-cell interference mitigation on BS cooperative system. Multi-cell system is interference limited system, due to the inevitable interference

of adjacent cell, when it takes the delay into account the interference is particularly severity. According to the characteristics of collaboration system, this paper gives a corresponding scheme, that is capture precision delay information and channel information through BS cooperate, followed by SLNR precoding among each base station to achieve interference mitigation. Simulation results indicate that the method effectively suppress inter-cell asynchronous interference, increase system performance, while it has lower complexity requirement and terminal is relative simplify. Simulation result also show that asynchronous interference significant impact on the system, further accurate analysis of asynchronous interference, establish asynchronous interference model and adopt the corresponding approach is necessary.

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