# Signal Detection for Joint Distributed Space-Time Coding in Asynchronous Cooperative Cellular Systems*

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**Abstract.** In this paper, a signal detection scheme using parallel interference cancellation (PIC) joint with successive interference cancellation (SIC) is proposed for an asynchronous cooperative cellular system utilizing the efficient joint distributed space-time coding (J-DSTC). Simulation results demonstrate that the proposed scheme outperforms the conventional J-DSTC equalization scheme in suppressing the interference at the destination upon receiving the jointly encoded transmit signals from the relay user using J-DSTC, including the information of both the relay user and the source user. It is also shown to be effective in removing the impact of inter-symbol-interference caused by the imperfect synchronization during the cooperative transmission. Meanwhile, a low structural and computational complexity is retained.

**Keywords:** parallel interference cancellation, successive interference cancellation, joint DSTC, imperfect synchronization.

## 1 Introduction

Multiple-input multiple-output (MIMO) techniques have been demonstrated to provide substantial capacity improvements to wireless communication systems, by using multiple antennas at both the transmitter and the receiver [1]. However, it is quite difficult to place multiple antennas in mobile units in cellular communication systems due to the size and cost limits. Cooperative communication technologies are then proposed to generate virtual MIMO arrays by transmitting signals from different locations to obtain the spatial gain [2].

Some cooperative transmit strategies and corresponding interference cancellation algorithms have been proposed [3-4], however, the cooperative nodes are selected only as relays of the source nodes, and are not considered to transmit their own information in these scenarios. To realize the space-time cooperation when considering all users

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transmit both their own information and their cooperative partners' information, distributed space-time coded systems with four transmit phases were introduced in [5], where mobile users transmitted cooperatively and utilized space-time coding in a distributed manner to improve the system performance. By reducing one phase in the cooperative transmission, [6] recently proposed a joint distributed space-time coding (J-DSTC) scheme to improve the transmit efficiency compared to [5], and achieves the same diversity order as [7]. Therefore, we consider a cooperative cellular system using the efficient J-STBC in this paper.

Most prior work on cooperation assumes synchronous communication between the signals transmitted from different cooperating users in the network. However, it is hard to achieve perfect synchronisation in practical systems. So considering J-DSTC in an asynchronous scenario is necessary. Limited work has been reported in the literature addressing the imperfect synchronization issue for cooperative communications [8-9]. These existing schemes either potentially incur a much higher computational complexity at the receiver, or did not consider the J-STBC transmit strategy.

Therefore, in this paper, we investigate a cellular system applying J-DSTC on the uplink. Each user of the cellular system selects a partner to transmit the combined signals. Signals transmitted from these two cooperating terminals are received asynchronously at BS. Such assumptions, unfortunately, will damage the orthogonality of the J-STBC and meanwhile lead to substantial performance degradation. Therefore, a signal detection scheme using parallel interference cancellation (PIC) [10-11] to remove the inter-symbol-interference (ISI) caused by the imperfect synchronization, jointly with successive interference cancellation (SIC) [12] to suppress the interference upon receiving the jointly encoded transmit signals from the relay user using J-DSTC, including the information of both the relay user and the source user. The proposed scheme is then shown to offer significant system performance improvement compared to that of using the conventional J-STBC equalization scheme [6], and still retains a relatively low structural and computational complexity under quasi-synchronization.

The paper is organized as follows. Section 2 describes the system model and the frame structure of an asynchronous cooperative system. In section 3, the proposed signal detection scheme is described. Simulation results are illustrated in section 4. Finally, conclusions are drawn in section 5.

## 2 System Model

### 2.1 System Model

The system model considered in this paper is similar to the system model in [6], in which two mobile users are selected as a group to transmit their information cooperatively to the base station (BS) in a cellular system. They both transmit their information to the same BS with only one antenna equipped on each of them. Both of the mobile users share the same frequency band and each user cannot transmit and receive at the same time. In this paper, four receive antennas are assumed to be equipped at the BS. The structures can be described more specifically in Figure 1.

## 2.2 Frame Structure

In the cooperative transmission process, each frame is divided into two subframes [6], a listening subframe and a cooperation subframe, as illustrated in Fig.1.

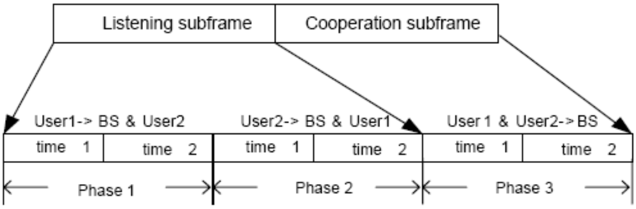

**Fig. 1.** Frame structure of the cooperation process

In the first phase of the listening subframe, mobile user1 transmits its information to the BS and mobile user2 simultaneously, while in the second phase of the listening subframe, mobile user2 transmits its information to the BS and user1. The cooperation subframe is shared by both user 1 and user2, to relay the information including both their own data and the cooperative partner's data [6].

## 2.3 Imperfect Synchronization Structure

Because of factors such as different propagation delays, the signals from user1 and user2 will normally arrive at BS at different time instants. As accurate synchronization is difficult or impossible [8, 9], there is normally a timing misalignment of $\tau$ between the received versions of these signals. Since a rough synchronization is always required, we assume here that $\tau$ is smaller than the symbol period T as shown in Fig.2. It will still cause 'intersymbol interference (ISI)' from neighboring symbols at D, owing to sampling/matched filtering (whatever kind of pulse shaping is used) [10].

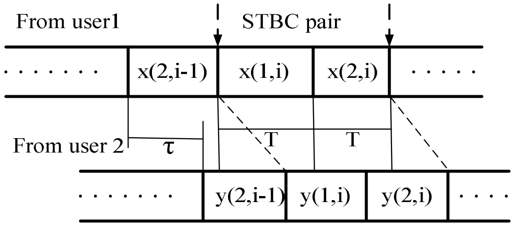

**Fig. 2.** Time delay (imperfect synchronization) between two users

# 3 Signal Detection Algorithm

## 3.1 Signal Model of J-STBC

We assume the interuser channels and the user-destination channels are independent of each other. All channels experience frequency flat fading and are quasi-static, i.e. they are fixed during a subframe and change independently in the next subframe. With the above assumptions, we now consider a discrete time model. In the first phase of the listening subframe, the first user broadcasts the *i*th pair of the transmitted symbols, $\mathbf{S}_k(i)$, which are selected from equally probable MPSK symbols. To simplify the expression we assume, without loss of generality, that $\mathbf{S}_k(i)$ contains two symbols, *e.g.* $\mathbf{S}_k(j,i) = [s_k(1,i), s_k(2,i)], k = 1,2, j = 1,2$, where *k* represents the *k*th mobile user in the cooperative process, and *j* represents the transmit symbol at the *j*th transmission time slot. Since four receive antennas configuration is considered in this paper, signal model is as follows.

**Listening Subframe.** At the BS, the received signals $\mathbf{r}_{k\mathrm{B}}(j,i), k = 1,2, j = 1,2$ during Phase1 and Phase2 corresponding to the *k*th user's direct transmission to the base station, are given as $\mathbf{r}_{k\mathrm{B}}(j,i) = \mathbf{h}_{k\mathrm{B}} \times \mathbf{S}_k(j,i) + \mathbf{n}_{k\mathrm{B}}$, where $\mathbf{h}_{k\mathrm{B}}$ is the channel gain between the *k*th user and the BS during the transmission of the listening subframe, and $\mathbf{n}_{k\mathrm{B}}$ is the additive Gaussian noise (AWGN) at the receiver. The received signal $\mathbf{r}_{k\mathrm{B}}(j,i)$ and the noise can be represented as $\mathbf{r}_{k\mathrm{B}} = \begin{bmatrix} r_{k\mathrm{B}1}(1),\ldots,r_{k\mathrm{B}n_R}(1) \\ r_{k\mathrm{B}1}(2),\ldots,r_{k\mathrm{B}n_R}(2) \end{bmatrix}^T$ and $\mathbf{n}_{k\mathrm{B}} = \begin{bmatrix} n_{k\mathrm{B}1}(1),\ldots,n_{k\mathrm{B}n_R}(1) \\ n_{k\mathrm{B}1}(2),\ldots,n_{k\mathrm{B}n_R}(2) \end{bmatrix}^T$, respectively. Meanwhile, the received signal at the cooperative users can be written respectively as $\mathbf{r}_{u_1u_2}(j) = h_1\mathbf{S}_1(j) + \mathbf{n}_1(j)$ and $\mathbf{r}_{u_2u_1}(j) = h_2\mathbf{S}_2(j) + \mathbf{n}_2(j)$.

Here $\mathbf{r}_{u_qu_p}(j), q = 1,2, p = 2,1, j = 1,2$ denotes the received signal at the pth user from the qth user during the listening subframe. $h_q, q = 1,2$ represents the channel gain from the qth user to its partner. $\mathbf{n}_k(j), k = 1,2$ is the AWGN.

**Cooperation Subframe.** In the cooperation subframe, both users act as relays and transmit the combination of the relay signals and their own information. The signal arriving at the destination is a linear combination of the signals from both the transmission paths. Without the loss of generality, we can assume that BS is synchronized to user1.The received signal at BS for cooperation subframe can be written as

$$\begin{aligned} \mathbf{r}(i) &= \begin{bmatrix} r_1(1,i),\ldots,r_{n_R}(1,i) \\ r_1(2,i),\ldots,r_{n_R}(2,i) \end{bmatrix}^T = \mathbf{H}_f \cdot \tilde{\mathbf{S}}(i) + \mathbf{I} + \mathbf{N} \\ &= \begin{bmatrix} h_{11},\ldots,h_{n_R1} \\ h_{12},\ldots,h_{n_R2} \end{bmatrix}^T \times \begin{bmatrix} \tilde{s}_1(1,i),\tilde{s}_1(2,i) \\ \tilde{s}_2(1,i),\tilde{s}_2(2,i) \end{bmatrix} + \mathbf{I} + \begin{bmatrix} n_1(1,i),\ldots,n_{n_R}(1,i) \\ n_1(2,i),\ldots,n_{n_R}(2,i) \end{bmatrix}^T \end{aligned} \tag{1}$$

where $r_m(l,i),\ l=1,2; m=1...n_R$ represents the received signal of the *m*th antenna at BS at the *l*th time slot. $h_{mk}, m=1,\cdots,4; k=1,2$ represents the channel gain between the *k*th user and the BS during the transmission of the cooperation subframe. The inter-symbol-interference (ISI) generated by the imperfect synchronization, **I**, is

$$\mathbf{I}(i)=\begin{bmatrix} h_{12}(\text{-}1)\tilde{s}_2^*(2,i\text{-}1) & h_{22}(\text{-}1)\tilde{s}_2^*(2,i\text{-}1) & \dots & h_{n_R2}(\text{-}1)\tilde{s}_2^*(2,i\text{-}1) \\ h_{12}^*(\text{-}1)\tilde{s}_2^*(1,i) & h_{22}(\text{-}1)\tilde{s}_2^*(1,i) & \dots & h_{n_R2}^*(\text{-}1)\tilde{s}_2^*(1,i) \end{bmatrix}^T \tag{2}$$

where $h_{m2}(-1)$ reflects the ISI from the previous symbol at the *m*th receive antenna and depends upon timing delay $\tau$ and the particular pulse shaping waveform used. Its relative strength can then be represented by ratio $\beta=|h_{m2}|^2/|h_{m2}(-1)|^2$ (dB).

$\tilde{s}_k(l,i)$ is the combined signal transmitted by the *k*th user at the *l*th time slot in the cooperation subframe, which can be described as

$$\begin{gathered}\tilde{\mathbf{S}}_1(i)=[\tilde{s}_1(1,i),\tilde{s}_1(2,i)]= \\ [\sqrt{\alpha_{11}}s_1(1,i)+\sqrt{\alpha_{12}}\sigma_2 r_{u_2u_1}^*(2,i),\sqrt{\alpha_{11}}s_1(2,i)-\sqrt{\alpha_{12}}\sigma_2 r_{u_2u_1}^*(1,i)]\end{gathered} \tag{3}$$

And

$$\begin{gathered}\tilde{\mathbf{S}}_2(i)=[\tilde{s}_2(1,i),\tilde{s}_2(2,i)]= \\ [\sqrt{\alpha_{22}}s_2(1,i)+\sqrt{\alpha_{21}}\sigma_1 r_{u_1u_2}^*(2,i),\sqrt{\alpha_{22}}s_2(2,i)-\sqrt{\alpha_{21}}\sigma_1 r_{u_1u_2}^*(1,i)]\end{gathered} \tag{4}$$

where $\alpha_{ij}, i=1,2, j=1,2$ denotes the symbol energy for the *i*th user's combined signal. $\sigma_i, i=1,2$ is an automatic gain control(AGC) parameter of non-regenerative systems, which is required at the relay mobile in order to prevent $r_{mn}(i)$ from saturating the relay amplifier. Specifically, we constrain the average radiated energy per symbol at the relay mobile to be 1 [5], a good choice is to adopt an AGC that employs

$$\sigma_k=\frac{h_k^*}{|h_k|}\sqrt{\frac{1}{\alpha_k|h_k|^2+N_k}},k=1,2 \tag{5}$$

where $\sigma_k$ is the transmit power in the first and second subframes (from user1 to user2 and from user2 to user1,respectively). $N_k$ represents the noise which has the same properties as $n_{nm}(j,i)$ .

At the destination, the received signal in (1) can be rewritten as (6)

$$\mathbf{r}(i)=\mathbf{H}\cdot\begin{bmatrix} s_1(1,i) \\ s_1^*(2,i) \\ s_2(1,i) \\ s_2^*(2,i) \end{bmatrix}+\mathbf{I}+\mathbf{Noise} \tag{6}$$

Where

$$\mathbf{H}=\begin{bmatrix} h_{11}\sqrt{\alpha_{11}} & h_{12}\sqrt{\alpha_{21}}\sigma_1 h_1^* & h_{12}\sqrt{\alpha_{22}} & h_{11}\sqrt{\alpha_{12}}\sigma_2 h_2^* \\ \text{-}(h_{12}\sqrt{\alpha_{21}}\sigma_1 h_1^*)^* & (h_{11}\sqrt{\alpha_{11}})^* & \text{-}(h_{11}\sqrt{\alpha_{12}}\sigma_2 h_2^*)^* & (h_{12}\sqrt{\alpha_{22}})^* \\ & \vdots & & \\ h_{n_R 1}\sqrt{\alpha_{11}} & h_{n_R 2}\sqrt{\alpha_{21}}\sigma_1 h_1^* & h_{n_R 2}\sqrt{\alpha_{22}} & h_{n_R 1}\sqrt{\alpha_{12}}\sigma_2 h_2^* \\ \text{-}(h_{n_R 2}\sqrt{\alpha_{21}}\sigma_1 h_1^*)^* & (h_{n_R 1}\sqrt{\alpha_{11}})^* & \text{-}(h_{n_R 1}\sqrt{\alpha_{12}}\sigma_2 h_2^*)^* & (h_{n_R 2}\sqrt{\alpha_{22}})^* \end{bmatrix} \tag{7}$$

And

$$\mathbf{Noise}=\begin{bmatrix} h_{11}\sqrt{\alpha_{12}}\sigma_2 n_2^*(2,i)+h_{12}\sqrt{\alpha_{21}}\sigma_1 n_1^*(2,i) \\ \left(-h_{11}\sqrt{\alpha_{12}}\sigma_2 n_2^*(1,i)-h_{12}\sqrt{\alpha_{21}}\sigma_1 n_1^*(1,i)\right)^* \\ h_{21}\sqrt{\alpha_{12}}\sigma_2 n_2^*(2,i)+h_{22}\sqrt{\alpha_{21}}\sigma_1 n_1^*(2,i) \\ \left(-h_{21}\sqrt{\alpha_{12}}\sigma_2 n_2^*(1,i)-h_{22}\sqrt{\alpha_{21}}\sigma_1 n_1^*(1,i)\right)^* \\ h_{31}\sqrt{\alpha_{12}}\sigma_2 n_2^*(2,i)+h_{32}\sqrt{\alpha_{21}}\sigma_1 n_1^*(2,i) \\ \left(-h_{31}\sqrt{\alpha_{12}}\sigma_2 n_2^*(1,i)-h_{32}\sqrt{\alpha_{21}}\sigma_1 n_1^*(1,i)\right)^* \\ h_{41}\sqrt{\alpha_{12}}\sigma_2 n_2^*(2,i)+h_{42}\sqrt{\alpha_{21}}\sigma_1 n_1^*(2,i) \\ \left(-h_{41}\sqrt{\alpha_{12}}\sigma_2 n_2^*(1,i)-h_{42}\sqrt{\alpha_{21}}\sigma_1 n_1^*(1,i)\right)^* \end{bmatrix}+\begin{bmatrix} n_1(1,i) \\ (n_1(2,i))^* \\ n_2(1,i) \\ (n_2(2,i))^* \\ n_3(1,i) \\ (n_3(2,i))^* \\ n_4(1,i) \\ (n_4(2,i))^* \end{bmatrix} \tag{8}$$

Equation (6) can further be expressed as

$$\mathbf{r}=\begin{bmatrix} \mathbf{R}_1 \\ \mathbf{R}_2 \\ \vdots \\ \mathbf{R}_{n_R} \end{bmatrix}=\mathbf{H}\begin{bmatrix} \mathbf{S}_1 \\ \mathbf{S}_2 \end{bmatrix}+\mathbf{I}+\mathbf{Noise}=\begin{bmatrix} \mathbf{A}_{11}\ \mathbf{A}_{12} \\ \mathbf{A}_{21}\ \mathbf{A}_{22} \\ \vdots \\ \mathbf{A}_{n_R 1}\mathbf{A}_{n_R 2} \end{bmatrix}\begin{bmatrix} \mathbf{S}_1 \\ \mathbf{S}_2 \end{bmatrix}+\mathbf{I}+\mathbf{Noise} \tag{9}$$

where $\mathbf{S}_k=\begin{bmatrix} s_k(1,i) \\ (s_k(2,i))^* \end{bmatrix}, k\in\{1,2\}$ consists of the two signals transmitted from the *k*th user and $\mathbf{R}_k=\begin{bmatrix} \mathrm{r}_k(1,i) \\ (\mathrm{r}_k(2,i))^* \end{bmatrix}$.

Moreover $\mathbf{A}_{kl}, k\in\{1,n_R\}, l\in\{1,2\}$, is the corresponding channel matrix from the *l*th user to the *k*th receive antenna, which have the Alamouti-like structures [13], i.e., $\mathbf{A}_{kl}=\begin{bmatrix} h_{1k}\sqrt{\alpha_{11}} & h_{k2}\sqrt{\alpha_{21}}\sigma_1 h_1^* \\ -(h_{k2}\sqrt{\alpha_{21}}\sigma_1 h_1^*)^* & (-h_{1k}\sqrt{\alpha_{11}})^* \end{bmatrix}$ for *l*=1, and $\mathbf{A}_{kl}=\begin{bmatrix} h_{2k}\sqrt{\alpha_{22}} & h_{k1}\sqrt{\alpha_{12}}\sigma_2 h_2^* \\ -(h_{k1}\sqrt{\alpha_{12}}\sigma_2 h_2^*)^* & (-h_{2k}\sqrt{\alpha_{22}})^* \end{bmatrix}$ for *l*=2.

## 3.2 SIC Processing

The received signal in (9) can be further written as:

$$\tilde{\mathbf{r}}(i) = \mathbf{H}\cdot\mathbf{s}(i) + \mathbf{I} + \mathbf{Noise}$$
$$= \begin{bmatrix} \mathbf{A}_{11}(1) \\ \mathbf{A}_{21}(1) \\ \vdots \\ \mathbf{A}_{n_R 1}(1) \end{bmatrix} s_1(1,i) + \ldots + \begin{bmatrix} \mathbf{A}_{12}(2) \\ \mathbf{A}_{22}(2) \\ \vdots \\ \mathbf{A}_{n_R 2}(2) \end{bmatrix} s_2^{*}(2,i) + \mathbf{I} + \mathbf{Noise} \tag{10}$$

where $\mathbf{A}_{kl}(x), x \in \{1,2\}$ denotes the $x$th column of $\mathbf{A}_{kl}$. Rewrite the above equation as

$$\tilde{\mathbf{r}}(i) = \mathbf{H}_{11}s_1(1,i) + \mathbf{H}_{12}s_1^{*}(2,i) + \mathbf{H}_{21}s_2(1,i) + \mathbf{H}_{22}s_2^{*}(2,i) + \mathbf{I} + \mathbf{Noise} \tag{11}$$

and then the SIC detection can be performed as follows:

The signals that have relatively larger channel power should be decoded before those with smaller power. For convenience, suppose the channel power has the ordering of $\|\mathbf{H}_{11}\|^2 \geq \|\mathbf{H}_{12}\|^2 \geq \|\mathbf{H}_{21}\|^2 \geq \|\mathbf{H}_{22}\|^2$, therefore, we begin with the detection of the first symbol of **s**, i.e. $s(l) = s_1(1) \quad l = 1$. The other undetected terms, $\mathbf{H}_{12}s_1^{*}(2), \mathbf{H}_{21}s_2(1), \mathbf{H}_{22}s_2^{*}(2)$ and Noise are treated as a Gaussian variable with matching mean and variance [7], such that (11) can be approximately expressed as:

$$\tilde{\mathbf{r}}(i) = \mathbf{H}_{11}s(l) + \boldsymbol{\eta} \qquad l = 1 \tag{12}$$

where $\boldsymbol{\eta}$ is a zero-mean complex Gaussian random variable with variance

$$\Lambda_1 = \mathrm{E}(\mathbf{h}_{2,4}\mathbf{h}_{2,4}^{H})\left|\bar{S}\right|^2 + \sigma_n^2(\Lambda_{\tilde{N}} \bullet \Lambda_{\tilde{N}}^{H}) + \sigma_n^2\mathbf{I}_t + \mathbf{I} \tag{13}$$

Here $\left|\bar{S}\right|^2$ represents the average power of the symbols in constellation $M$. $\mathbf{I}_t$ is a $t \times t$ identity matrix with $t=2\,n_R$. $\Lambda_{\tilde{N}}$ is a $t \times 1$ Matrix, reshaped from the following:

$$\Lambda_{\tilde{N}t} = \boldsymbol{H}_f \cdot \tilde{\boldsymbol{N}}_d = \begin{bmatrix} h_{11}, \ldots, h_{n_R 1} \\ h_{12}, \ldots, h_{n_R 2} \end{bmatrix}^T \cdot \begin{bmatrix} \sqrt{\alpha_{12}}\sigma_2 & -\sqrt{\alpha_{12}}\sigma_2 \\ \sqrt{\alpha_{21}}\sigma_1 & -\sqrt{\alpha_{21}}\sigma_1 \end{bmatrix} \tag{14}$$

All the possible modulated symbols related to $s(l) \quad l = 1$ can be examined by:

$$\tilde{s}(l) = \arg\min_{s(l)\in M} \left|[\tilde{\mathbf{r}} - \mathbf{H}_{11}s(l)]^{H}\Lambda_1^{-1}[\tilde{\mathbf{r}} - \mathbf{H}_{11}s(l)]\right| \quad l = 1 \tag{15}$$

where the calculation of $\Lambda_1^{-1}$ can be greatly simplified using the matrix inversion lemma. As a result, $\tilde{s}(l) \quad l = 1$ can be estimated by choosing the smallest value of (15).

In the $l$th detection, the previously detected symbols can be used to decode the following symbol. Again, the undetected terms should be treated as a Gaussian variable. The following equation can be applied to calculate the probabilities for $\tilde{s}_1^{*}(2,i), \quad \tilde{s}_2^{*}(2,i)$ successively:

$$\tilde{s}(l,i) = \arg\min_{s(l)\in M} \left|[\tilde{\mathbf{r}} - \mathbf{H}_{i2}\tilde{\mathbf{s}}_i(2,i) - \mathbf{H}_{i1}s_i(1,i)]^H \cdots \right.$$
$$\left. \Lambda_l^{-1}[\tilde{\mathbf{r}} - \mathbf{H}_{i2}\tilde{\mathbf{s}}_i(2,i) - \mathbf{H}_{i1}s_i(1,i)]\right| \tag{16}$$

where $\tilde{\mathbf{s}}(l,i) = [\tilde{s}_1(1,i)...\tilde{s}_2(2,i)]$ $l = 1,\cdots,4$ and $\Lambda_l^{-1}$ can be simplified similarly. The same detection process will be repeated until each pair of the transmitted symbols from each user during the cooperation transmission has been detected. The signals received during the listening subframe still contains valuable information even if the direct transmission fails, therefore should be combined with the detected signals from the cooperation subframe to improve the accuracy of the estimated transmitted symbols from both users. Applying the conventional maximum ratio combining (MRC) method to $\mathbf{r}_{k\mathrm{B}}$, and the combined signal can be expressed as

$$\begin{aligned} \mathbf{g}_1 &= [g_1(1) \quad g_1(2)]^T = \mathbf{h}_{1\mathrm{B}}^H\mathbf{r}_{1\mathrm{B}} + [\tilde{s}_1(1) \quad \tilde{s}_1(2)]^T \\ \mathbf{g}_2 &= [g_2(1) \quad g_2(2)]^T = \mathbf{h}_{2\mathrm{B}}^H\mathbf{r}_{2\mathrm{B}} + [\tilde{s}_2(1) \quad \tilde{s}_2(2)]^T \end{aligned} \tag{17}$$

Finally, the detected transmitted symbols of the *k*th user can be obtained by choosing the smallest value from the following:

$$s_k(j) = \arg\{\min_{s_m\in M}\left|g_k(j) - \lambda s_m\right|^2\} \qquad k = 1,2, j = 1,2 \tag{18}$$

where $\lambda = 1 + \left|h_{k\mathrm{B}1}\right|^2 + ... + \left|h_{k\mathrm{B}n_R}\right|^2$.

### 3.3 PIC Processing Joint with SIC

Since ISI is included in the received signal $\mathbf{r}(i)$ and affects the performance of the SIC processing significantly, we hereby propose to use PIC processing in the signal detection to improve the accuracy of $\mathbf{r}(i)$, and hence improve the performance of the SIC processing. The PIC iteration process, which has been applied to the co-located STBC system [12], can then be used to mitigate the impact of I as follows.

**Initialization. *k*=0**

— For convenience, we first reshape $\mathbf{r}(i)$ as follows,

$$\mathbf{r}(i) = \begin{bmatrix} r_1(1,i) & r_2(1,i) & \cdots & r_{n_R}(1,i) \\ r_1^*(2,i) & r_2^*(2,i) & \cdots & r_{n_R}^*(2,i) \end{bmatrix}^T \tag{19}$$

— From the received signal $\mathbf{r}(i)$, calculate $\mathbf{r}'^{(0)}(i) = [\mathbf{r}(1,i) - \mathbf{I}(1,i), \mathbf{r}^*(2,i)]^T$, where $\mathbf{r}(j,i)$, $j\in\{1,2\}$ represents the *j*th row of $\mathbf{r}(i)$ and $\mathbf{I}(j,i)$ represents the *j*th row of $\mathbf{I}(i)$ in (2).

— Reshape $\mathbf{r}'^{(0)}(i)$ into a $8\times 1$ matrix. Calculate $\tilde{\mathbf{s}}^{(0)}(i)$ using the SIC detector introduced in the above subsection with $\mathbf{r}'^{(0)}(i)$.

**Iteration. *k=1, …, K***

— Reshape $\mathbf{r}(i)$ as the first step in the initialization stage.

— Calculate

$$\mathbf{r}'^{(k)}(i) = [\mathbf{r}(1,i) - \mathbf{I}(1,i), \mathbf{r}^*(2,i) - \mathbf{I}^{(k-1)}(2,i)]^T \tag{20}$$

where $\mathbf{I}^{(k-1)}(2,i) = h_2^*(-1)[s^{(k-1)}(2,i)]^*$.

— Transform $\mathbf{r}'^{(k)}(i)$ into a $8\times1$ matrix. Calculate $\tilde{\mathbf{s}}^{(k)}(i)$ by SIC with $\mathbf{r}'^{(k)}(i)$.

For $k = 0$, the computation is the same as the conventional STBC detector. For $K$ iterations, the complexity issue refers to [4]. As normally $K = 2$ or 3, the increase in computational complexity is very moderate.

## 4 Simulation Results

Simulation results are shown in this section to demonstrate the performance of the proposed signal detection algorithm using PIC jointly with SIC. Four receive antennas are considered to be equipped at the BS. The modulation scheme used is 8PSK, and $\beta = 0$ (dB).

In Fig.3, the BER performance of using the proposed signal detection scheme is compared with that of using the linear filter [6] and with the PIC detector joint with the linear filter [6] under imperfect synchronization, and with that of using the linear filter [6] under perfect synchronization. It can be observed from the figure that our proposed scheme in the asynchronous scenario outperforms the existing linear filter [6] significantly, even when the linear filter is under perfect synchronization, and the PIC detector is very effective in removing the ISI.

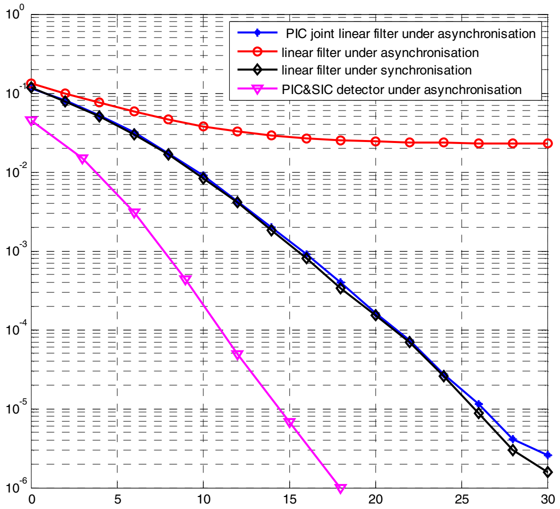

**Fig. 3.** BER comparisons of PIC joint SIC detector, PIC detector joint linear filter, linear filter detector under asynchronization and linear filter detector under synchronization

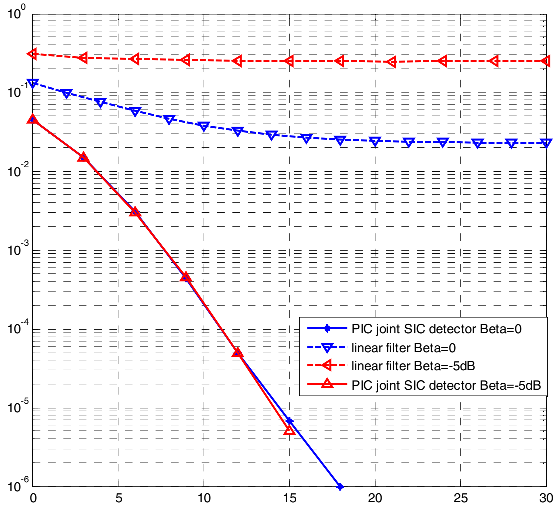

**Fig. 4.** BER comparison of PIC joint SIC detector and linear filter with different Beta values under imperfect synchronization

Fig.4 shows the BER performance comparisons between the proposed scheme and the existing scheme in [6] under different $\beta$ values. It is shown that the smaller the $\beta$ values is, the worse the ISI is caused by the imperfect synchronization during cooperative transmission. While the performance of using the existing linear filter [6] degrades significantly when the $\beta$ value decreases, the performance of using the proposed signal detection method is nearly the same, and great performance improvement is achieved in the case of different $\beta$ values.

## 5 Conclusion

In this paper, a signal detection scheme using both PIC and SIC was proposed for Joint-DSTC under imperfect synchronization in a cellular system. By using the Joint-DSTC, the cooperative process can reduce the transmit frames and improve the efficiency of the whole system compared with the conventional DSTC scheme. The proposed signal detection scheme was shown to offer significant performance improvement for the imperfect synchronized cooperative cellular system using J-DSTC, but still retain a relatively low structural and computational complexity.

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