Full Interference Cancellation for An Asymptotically Full Rate Asynchronous Cooperative Four Relay Network

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***Abstract*—We propose the use of simple full interference cancellation (FIC) and orthogonal frequency-division multiplexing (OFDM) within a two-hop asynchronous cooperative four relay network. This approach can achieve the full available diversity and asymptotically full rate. The four relay nodes are arranged as two groups of two relay nodes with offset transmission scheduling. Therefore, the source can serially transmit data to the destination and the overall rate can approach one when the number of samples is large. However, the four-path relay scheme may suffer from inter-relay interference which is caused by the simultaneous transmission of the source and another group of relays. The FIC approach is therefore used to remove inter-relay interference; OFDM with cyclic prefix (CP) and time-reversion is applied at the source and relays respectively, in order to combat timing errors. Uncoded and coded bit error rate simulations confirm the utility of the scheme.**

I. Introduction

Cooperative relays are an important physical layer concept for mobile wireless ad hoc networks to achieve higher throughput, lower energy consumption and/or longer lifetime [1]. Furthermore, relay nodes can not only provide independent channels between the source and the destination, to leverage spatial diversity [2], but they also can help two users with no or weak direct connection to attain a robust link.

Space-time coding is an effective technique to exploit spatial diversity not only for multiple-input multiple-output (MIMO) point-to-point systems but also for cooperative ones [3]. While full diversity achieving space-time codes for MIMO systems achieve full spatial diversity for synchronous cooperative systems, their performance can be degraded greatly in the presence of asynchronism. Such asynchronism results from the nodes being in different locations and mismatch between their individual oscillators [4]. To further improve end-to-end performance in cooperative communications outer coding and decoding can be added at the source and destination [5].

The scheme in [6] achieves increasing robustness to asynchronism with a simple space-time coding cooperative scheme though the use of OFDM and a CP. The method is designed for flat-fading quasi-static channels. However, its end-to-end transmission rate is only 0.5.

In order to improve this, in our work, two relays are added between the source (S) and the destination (D). As is shown in Fig.1, there is one source node and one destination node and four relay nodes (R1, R2, R3 and R4). Source node and each relay node has a single antenna, which can be used for either transmission or reception, whereas the destination node has multiple antennas, and therefore the structure is more suitable for up-link communications. At any transmission step, the signal can be sent from the source node (S) to relay one (R1) and relay three (R3), at the same time, relay two (R2) and relay four (R4) transmit earlier data, which is transmitted from the source at the previous step, to the destination node. Using this offset transmission method the source can continuously send data to the relay nodes. Therefore, the full transmission rate can be potentially achieved when the number of transmitted samples is large. However, inter-relay interference (IRI) is a problem in this scheme. The data received at R1 and R3 from the source are corrupted by the data from R2 and R4, because R2 and R4 send the data simultaneously with the source in the same step. As a result, inter-relay interference can degrade the performance [7].

In this paper, we therefore propose a full interference cancellation (FIC) with OFDM scheme so that the IRI terms can be removed totally and robust communication can thereby be obtained, and using outer coding in the source and destination can improve end-to-end performance of the cooperative communication scheme.

II. STBC scheme for an asynchronous cooperative four relay network

The relay model for the four-path relay scheme is illustrated in Fig.1. Firstly, the signal is encoded by using convolution coding and interleaving. Then quadrature phase-shift keying (QPSK) mapping is applied to modulate the input signal. After the asynchronous relay system, QPSK unmapping, Viterbi decoding and deinterleaving are used for demodulation to yield the information signal. Finally, the end-to-end bit error rate (BER) can be obtained by comparing the source signal and received signal, where f_i $(i = 1, ..., 4)$ denote the channels from the transmitter to the four relays and g_i $(i = 1, ..., 4)$ denote the channels from the four relays to the destination. We assume that τ_1 and τ_2 are delays from R3 to D and R4 to D, respectively. There is no direct link between the source and the destination as path loss or shadowing renders it unusable. We assume the inter-relay channels are reciprocal, i.e. the gains from R1 and R3 to R2 and R4 are the same as those from R2 and R4 to R1 and R3, which are denoted h12, h23, h34 and h14. We assume that the channels are quasi-static flat-fading: f_i and g_i are independent and identically distributed (i.i.d) zero-mean and unit-variance complex Gaussian random variables.

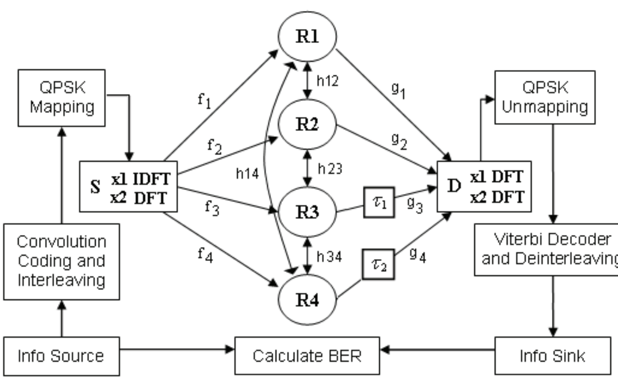

Fig. 1. An asynchronous outer-coded cooperative four relay network model

A. Implementation at the source node

At the source node, two consecutive OFDM blocks $\mathbf{x}_1 = [x_{0,1}, x_{1,1}, \ldots, x_{N-1,1}]^T$ and $\mathbf{x}_2 = [x_{0,2}, x_{1,2}, \ldots, x_{N-1,2}]^T$ are broadcasted, which are composed of a set of N modulated complex symbols $x_{i,j}$, which are modulated into time domain samples using IDFT and DFT operations, respectively, where $(.)^T$ denotes the transpose operation and j = 1 or 2. Therefore, $\mathbf{X}_1$ = IDFT($\mathbf{x}_1$) and $\mathbf{X}_2$ = DFT($\mathbf{x}_2$). Then each block is preceded by a CP with length l_{cp}. Thus, each OFDM symbol consists of $L_s = N + l_{cp}$ samples. Assume that the length of the CP is not less than the maximum of the possible relative timing errors (τ_{max}) of the signals which arrive at the destination node from the relay nodes. Denote the two OFDM symbols $\mathbf{X}_1$ and $\mathbf{X}_2$ with the corresponding CP as $\overline{\mathbf{X}}_1$ and $\overline{\mathbf{X}}_2$.

B. Implementation at the relay nodes

At the relay nodes, assume the channel coefficients are constant during two OFDM symbol intervals. Then the received signals at the i^{th} $(i = 1, ..., 4)$ relays for two successive OFDM symbol duration can be written as

$$\mathbf{Y}_{ij} = \overline{\mathbf{X}}_j f_i + \mathbf{n}_{ij} \tag{1}$$

where j = 1 or 2, and $\mathbf{n}_{ij}$ is the corresponding additive white Gaussian noise (AWGN) at the i^{th} relay node with zero mean and unit variance, in two successive OFDM symbol durations, respectively. Let P_s denote the transmission power at the source node. Then the mean power of signal $\mathbf{Y}_{ij}$ at the relay node is $P_s + 1$ because of the unit variance assumption of the additive noise $\mathbf{n}_{ij}$ from the source node to a relay node in (1). P_r denotes the average transmission power at every relay node. The optimum power allocation proposed in [8] is used in this scheme, we have

$$P_s = RP_r = 0.5P \tag{2}$$

where P is the total transmission power in the whole scheme and R is equal to 2. The relay nodes will process and transmit the received noisy signal according to the i^{th} column of the relay encoding matrix S,

$$S = \beta \begin{bmatrix} \mathbf{Y}_{11} & -\mathbf{Y}_{32}^* \\ \zeta(\mathbf{Y}_{12}) & \zeta(\mathbf{Y}_{31}^*) \end{bmatrix} \text{ or } \beta \begin{bmatrix} \mathbf{Y}_{21} & -\mathbf{Y}_{42}^* \\ \zeta(\mathbf{Y}_{22}) & \zeta(\mathbf{Y}_{41}^*) \end{bmatrix} \tag{3}$$

where $\beta = \sqrt{\frac{P_r}{P_s+1}}$, $(.)^*$ denotes complex conjugation, and $\zeta(.)$ represents the time-reversal of the signal, i.e., $\zeta(\mathbf{Y}(n))$ $= \mathbf{Y}(L_s - n)$, $n = 0, 1, \ldots, L_s - 1$, and $\mathbf{Y}(L_s) = \mathbf{Y}(0)$.

C. Implementation at the destination node

At the destination node, firstly, the CP is removed for each OFDM symbol as in a conventional OFDM system. Then the reordering process needs to be used on the second OFDM received frame to modify for the misalignment caused by the time-reversal in (3), which is shifting the last l_{cp} samples of the N-point vector as the first l_{cp} samples. After that, the received signals are transformed by the N-point DFT. As mentioned before, because of timing errors, the signals from R3 or R4 arrive at the destination node $\tau_i (i = 1, 2)$ samples later than the signals from R1 or R2, respectively. Since l_{cp} is not less than τ_{max}, we can still maintain the orthogonality between the subcarriers. The delay in the time domain corresponds to a phase change in the frequency domain,

$$\mathbf{u}^{\tau_i} = \left[u_0^{\tau_i}, u_1^{\tau_1}, \ldots, u_{N-1}^{\tau_i}\right]^T \tag{4}$$

where $u_k^{\tau_i} = exp(-j2\pi k\tau_i/N)$ and $k = 0, 1, \ldots, N-1$. Let $\mathbf{Z}_1 = [Z_{0,1}, Z_{1,1}, \ldots, Z_{N-1,1}]^T$ and $\mathbf{Z}_2 = [Z_{0,2}, Z_{1,2}, \ldots,$ $Z_{N-1,2}]^T$ be the received signals for two successive OFDM blocks at the destination node after the CP removal and the DFT transformation. We let F_1 = DFT(IDFT($\mathbf{x}_1$)), F_2 = DFT($-$(IDFT($\mathbf{x}_2$))*), F_3 = DFT(ζ(DFT($\mathbf{x}_2$))) and F_4 = DFT(ζ((IDFT($\mathbf{x}_1$))*)). Taking hop 1 as an example, $\mathbf{Z}_1$ and $\mathbf{Z}_2$ can be written as

$$\mathbf{Z}_1 = \beta[F_1 f_1 g_1 + F_2 \circ \mathbf{u}^{\tau_1} f_3^* g_3 + \mathbf{N}_{11} g_1 + \mathbf{N}_{32} \circ \mathbf{u}^{\tau_1} g_3 + \mathbf{W}_1] \tag{5}$$

$$\mathbf{Z}_2 = \beta[F_3 f_1 g_1 + F_4 \circ \mathbf{u}^{\tau_1} f_3^* g_3 + \mathbf{N}_{12} g_1 + \mathbf{N}_{31} \circ \mathbf{u}^{\tau_1} g_3 + \mathbf{W}_2] \tag{6}$$

where $\circ$ is the Hadamard product, and $\mathbf{N}_{ij} = (N_{k,ij})$ are the DFTs of $\mathbf{n}_{ij}$ and $\mathbf{W}_j = (W_{k,j})$ are AWGN terms at the destination node with zero-mean and unit-variance. Using (DFT(x))* = IDFT(x)*, (IDFT(x))* = DFT(x^*) and DFT(ζ(DFT(x))) = IDFT(DFT(x)), (5) and (6) can be rewritten as in the following Alamouti code at each subcarrier $k, 0 \le k \le N-1$

$$\begin{bmatrix} Z_{k,1} \\ Z_{k,2} \end{bmatrix} = \beta \begin{bmatrix} x_{k,1} & -x_{k,2}^* \\ x_{k,2} & x_{k,1}^* \end{bmatrix} \begin{bmatrix} f_1 g_1 \\ u_k^{\tau_1} f_3^* g_3 \end{bmatrix} + \begin{bmatrix} v_{k,1} \\ v_{k,2} \end{bmatrix} \quad (7)$$

where $v_{k,j} = \beta(N_{k,1j} g_1 + N_{k,3j} \circ u_k^{\tau_1} g_3) + W_{k,j}$. Then the Alamouti fast symbolwise ML decoding can be used at the destination node.

III. Interference cancellation scheme

In this part, we propose a full interference cancellation scheme to remove completely the inter-relay inference from the other relays. Similarly to that in [9], we assume that the relay nodes R1 and R3 receive at time slot $n-1$, at the same time, and the relay nodes R2 and R4 send the signal to the destination nodes. And we assume all of the channel information is known by the receiver.

Therefore, we first consider the received signal at the destination at time slot $n-1$ as:

$$\mathbf{Z}_{n-1,1} = \beta \mathbf{Y}_{21} g_2(n-1) + \beta(-\mathbf{Y}_{42}^*) g_4(n-1)\mathbf{u}^{\tau_2} + \mathbf{W}_1$$
$$\mathbf{Z}_{n-1,2} = \beta\zeta(\mathbf{Y}_{22}) g_2(n-1) + \beta\zeta(\mathbf{Y}_{41}^*) g_4(n-1)\mathbf{u}^{\tau_2} + \mathbf{W}_2 \quad (8)$$

where $\mathbf{W}_1$ is the Gaussian noise at the destination, $\mathbf{Y}_{21}$ and $\mathbf{Y}_{42}$, $\mathbf{Y}_{22}$ and $\mathbf{Y}_{41}$ are the received signals at R2 and R4 at time slot $n-2$, respectively, and they are encoded by using (3), which are given by:

$$\mathbf{Y}_{21} = \overline{\mathbf{X}}_1 f_2(n-2) + \mathbf{N}_{21} + \mathbf{Y}_{11} h_{12} + (-\mathbf{Y}_{32}^*) h_{32}$$
$$\mathbf{Y}_{41} = \overline{\mathbf{X}}_1 f_4(n-2) + \mathbf{N}_{41} + \mathbf{Y}_{11} h_{14} + (-\mathbf{Y}_{32}^*) h_{34}$$
$$\mathbf{Y}_{22} = \overline{\mathbf{X}}_2 f_2(n-2) + \mathbf{N}_{22} + \zeta(\mathbf{Y}_{12}) h_{12} + \zeta(\mathbf{Y}_{31}^*) h_{32}$$
$$\mathbf{Y}_{42} = \overline{\mathbf{X}}_2 f_4(n-2) + \mathbf{N}_{42} + \zeta(\mathbf{Y}_{12}) h_{14} + \zeta(\mathbf{Y}_{31}^*) h_{34} \quad (9)$$

We also can obtain the receiver signal at the destination at time slot $n-2$ as:

$$\mathbf{Z}_{n-2,1} = \beta \mathbf{Y}_{11} g_1(n-2) + \beta(-\mathbf{Y}_{32}^*) g_3(n-2)\mathbf{u}^{\tau_1} + \mathbf{W}_1$$
$$\mathbf{Z}_{n-2,2} = \beta\zeta(\mathbf{Y}_{12}) g_1(n-2) + \beta\zeta(\mathbf{Y}_{31}^*) g_3(n-2)\mathbf{u}^{\tau_1} + \mathbf{W}_2 \quad (10)$$

If multiple antennas were available at the destination node, and given that the relays are sufficiently spatially separated, we make the assumption that it is possible to separate out the individual relay components within $\mathbf{Z}_{n-2,1}$ and $\mathbf{Z}_{n-2,2}$

$$\mathbf{Z}_{n-2,1} = \mathbf{Z}_{n-2,1,1} + \mathbf{Z}_{n-2,1,2}\mathbf{u}^{\tau_1} + \mathbf{W}_1$$
$$\mathbf{Z}_{n-2,2} = \mathbf{Z}_{n-2,2,1} + \mathbf{Z}_{n-2,2,2}\mathbf{u}^{\tau_1} + \mathbf{W}_2 \quad (11)$$

as given by

$$\mathbf{Z}_{n-2,1,1} = \beta \mathbf{Y}_{11} g_1(n-2) \qquad \mathbf{Z}_{n-2,1,2} = \beta(-\mathbf{Y}_{32}^*) g_3(n-2)$$
$$\mathbf{Z}_{n-2,2,1} = \beta\zeta(\mathbf{Y}_{12}) g_1(n-2) \qquad \mathbf{Z}_{n-2,2,2} = \beta\zeta(\mathbf{Y}_{31}^*) g_3(n-2)$$

where the noise term is assumed to be insignificant.

So

$$\mathbf{Y}_{11} = \frac{\mathbf{Z}_{n-2,1,1}}{\beta g_1(n-2)} \qquad -\mathbf{Y}_{32}^* = \frac{\mathbf{Z}_{n-2,1,2}}{\beta g_3(n-2)}$$
$$\zeta(\mathbf{Y}_{12}) = \frac{\mathbf{Z}_{n-2,2,1}}{\beta g_1(n-2)} \qquad \zeta(\mathbf{Y}_{31}^*) = \frac{\mathbf{Z}_{n-2,2,2}}{\beta g_3(n-2)} \quad (12)$$

Finally, substituting (12) and (9) into (8) gives:

$$\begin{aligned}\mathbf{Z}_{n-1,1} = \beta((&\overline{\mathbf{X}}_1 f_2(n-2) + \mathbf{N}_{21}) g_2(n-1) + \\ & g_2(n-1)\left(\frac{\mathbf{Z}_{n-2,1,1}}{\beta g_1(n-2)} h_{12} + \frac{\mathbf{Z}_{n-2,1,2}}{\beta g_3(n-2)} h_{32}\right) - \\ & (\overline{\mathbf{X}}_2^* f_4^*(n-2) + \mathbf{N}_{42}^*) g_4(n-1)\mathbf{u}^{\tau_2} - g_4(n-1) \\ & \mathbf{u}^{\tau_2}\left(\frac{\mathbf{Z}_{n-2,2,1}}{\beta g_1(n-2)} h_{14} + \frac{\mathbf{Z}_{n-2,2,2}}{\beta g_3(n-2)} h_{34}\right)^*) + \mathbf{W}_1\end{aligned}$$

$$\begin{aligned}\mathbf{Z}_{n-1,2} = \beta((&\zeta(\overline{\mathbf{X}}_2 f_2(n-2)) + \zeta(\mathbf{N}_{22})) g_2(n-1) + \\ & g_2(n-1)\zeta\left(\frac{\mathbf{Z}_{n-2,2,1}}{\beta g_1(n-2)} h_{12} + \frac{\mathbf{Z}_{n-2,2,2}}{\beta g_3(n-2)} h_{32}\right) + \\ & (\zeta(\overline{\mathbf{X}}_1^* f_4^*(n-2)) + \zeta(\mathbf{N}_{41}^*)) g_4(n-1)\mathbf{u}^{\tau_2} + g_4(n-1) \\ & \mathbf{u}^{\tau_2}\zeta\left(\frac{\mathbf{Z}_{n-2,1,1}}{\beta g_1(n-2)} h_{14} + \frac{\mathbf{Z}_{n-2,1,2}}{\beta g_3(n-2)} h_{34}\right)^*) + \mathbf{W}_2\end{aligned} \quad (13)$$

From (13), we can find the inter-relay interference as a recursive term in the received signal at the destination nodes. For example, (14), (15), (16) and (17) are IRI terms, which are functions only of the previous output values.

$$\beta g_2(n-1)\left(\frac{\mathbf{Z}_{n-2,1,1}}{\beta g_1(n-2)} h_{12} + \frac{\mathbf{Z}_{n-2,1,2}}{\beta g_3(n-2)} h_{32}\right) \quad (14)$$

$$\beta g_4(n-1)\mathbf{u}^{\tau_2}\left(\frac{\mathbf{Z}_{n-2,2,1}}{\beta g_1(n-2)} h_{14} + \frac{\mathbf{Z}_{n-2,2,2}}{\beta g_3(n-2)} h_{34}\right)^* \quad (15)$$

$$\beta g_2(n-1)\zeta\left(\frac{\mathbf{Z}_{n-2,2,1}}{\beta g_1(n-2)} h_{12} + \frac{\mathbf{Z}_{n-2,2,2}}{\beta g_3(n-2)} h_{32}\right) \quad (16)$$

$$\beta g_4(n-1)\mathbf{u}^{\tau_2}\zeta\left(\frac{\mathbf{Z}_{n-2,1,1}}{\beta g_1(n-2)} h_{14} + \frac{\mathbf{Z}_{n-2,1,2}}{\beta g_3(n-2)} h_{34}\right)^* \quad (17)$$

Therefore, we can completely remove these terms from (13) in order to cancel the IRI at the receiver, which are given by:

$$\begin{aligned}\mathbf{Z}'_{n-1,1} = \beta((&\overline{\mathbf{X}}_1 f_2(n-2) + \mathbf{N}_{21}) g_2(n-1) - \\ & (\overline{\mathbf{X}}_2^* f_4^*(n-2) + \mathbf{N}_{42}^*) g_4(n-1)\mathbf{u}^{\tau_2}) + \mathbf{W}_1\end{aligned}$$

$$\begin{aligned}\mathbf{Z}'_{n-1,2} = \beta((&\zeta(\overline{\mathbf{X}}_2 f_2(n-2)) + \zeta(\mathbf{N}_{22})) g_2(n-1) + \\ & (\zeta(\overline{\mathbf{X}}_1^* f_4^*(n-2)) + \zeta(\mathbf{N}_{41}^*)) g_4(n-1)\mathbf{u}^{\tau_2}) + \mathbf{W}_2\end{aligned} \quad (18)$$

As such, (18) has no IRI, with the desired signal and the noise. However, we find a very interesting relationship for the received signal at the destination at the different odd-even time slots. And then we use the same method to obtain the received signal at time slot n at the destination node and cancel completely the IRI.

$$\begin{aligned}\mathbf{Z}_{n,1} &= \beta((\overline{\mathbf{X}}_1 f_1(n-1)+\mathbf{N}_{11})g_1(n)+\\ &g_1(n)\left(\frac{\mathbf{Z}_{n-1,1,1}}{\beta g_2(n-1)}h_{21}+\frac{\mathbf{Z}_{n-1,1,2}}{\beta g_4(n-1)}h_{41}\right)-\\ &(\overline{\mathbf{X}}_2^* f_3^*(n-1)+\mathbf{N}_{32}^*)g_3(n)\mathbf{u}^{\tau_1}-g_3(n)\\ &\mathbf{u}^{\tau_1}\left(\frac{\mathbf{Z}_{n-1,2,1}}{\beta g_2(n-1)}h_{23}+\frac{\mathbf{Z}_{n-1,2,2}}{\beta g_4(n-1)}h_{43}\right)^*)+\mathbf{W}_1\end{aligned} \tag{19}$$

$$\begin{aligned}\mathbf{Z}_{n,2} &= \beta((\zeta(\overline{\mathbf{X}}_2 f_1(n-1))+\zeta(\mathbf{N}_{12}))g_1(n)+\\ &g_1(n)\zeta\left(\frac{\mathbf{Z}_{n-1,2,1}}{\beta g_2(n-1)}h_{21}+\frac{\mathbf{Z}_{n-1,2,2}}{\beta g_4(n-1)}h_{41}\right)+\\ &(\zeta(\overline{\mathbf{X}}_1^* f_3^*(n-1))+\zeta(\mathbf{N}_{31}^*))g_3(n)\mathbf{u}^{\tau_1}+g_3(n)\\ &\mathbf{u}^{\tau_1}\zeta\left(\frac{\mathbf{Z}_{n-1,1,1}}{\beta g_2(n-1)}h_{23}+\frac{\mathbf{Z}_{n-1,1,2}}{\beta g_4(n-1)}h_{43}\right)^*)+\mathbf{W}_2\end{aligned} \tag{20}$$

From (19) and (20), we also can easily find the IRI as a recursive term in the received signal at the destination node. For example, (21), (22), (23) and (24) are IRI terms.

$$\beta g_1(n)\left(\frac{\mathbf{Z}_{n-1,1,1}}{\beta g_2(n-1)}h_{21}+\frac{\mathbf{Z}_{n-1,1,2}}{\beta g_4(n-1)}h_{41}\right) \tag{21}$$

$$\beta g_3(n)\mathbf{u}^{\tau_1}\left(\frac{\mathbf{Z}_{n-1,2,1}}{\beta g_2(n-1)}h_{23}+\frac{\mathbf{Z}_{n-1,2,2}}{\beta g_4(n-1)}h_{43}\right)^* \tag{22}$$

$$\beta g_2(n-1)\zeta\left(\frac{\mathbf{Z}_{n-1,2,1}}{\beta g_1(n-2)}h_{12}+\frac{\mathbf{Z}_{n-1,2,2}}{\beta g_3(n-2)}h_{32}\right) \tag{23}$$

$$\beta g_4(n-1)\mathbf{u}^{\tau_2}\zeta\left(\frac{\mathbf{Z}_{n-1,1,1}}{\beta g_1(n-2)}h_{14}+\frac{\mathbf{Z}_{n-1,1,2}}{\beta g_3(n-2)}h_{34}\right)^* \tag{24}$$

Therefore, we can completely remove these terms from (19) and (20) by using the same method, which are given by:

$$\begin{aligned}\mathbf{Z}'_{n,1} &= \beta((\overline{\mathbf{X}}_1 f_1(n-1)+\mathbf{N}_{11})g_2(n)-\\ &(\overline{\mathbf{X}}_2^* f_3^*(n-1)+\mathbf{N}_{32}^*)g_3(n)\mathbf{u}^{\tau_1})+\mathbf{W}_1\\ \mathbf{Z}'_{n,2} &= \beta((\zeta(\overline{\mathbf{X}}_2 f_1(n-1))+\zeta(\mathbf{N}_{12}))g_1(n)+\\ &(\zeta(\overline{\mathbf{X}}_1^* f_3^*(n-1))+\zeta(\mathbf{N}_{31}^*))g_3(n)\mathbf{u}^{\tau_1})+\mathbf{W}_2\end{aligned} \tag{25}$$

Compared with (18) and (25), we find they have the same structure. However, according to the different the offset time slots, the alternate channels are switched regularly. Therefore, the transmission symbols can be easily detected by the fast symbol-wise ML decoding.

The FIC scheme has the following advantages: firstly, the FIC can completely remove the inter-relay interference. Secondly, the FIC only depends on the previous received signal without error propagation. Finally, only four buffers are required to store the previous received signals, i.e. $\mathbf{Z}_{n-1,1,1}$, $\mathbf{Z}_{n-1,1,2}$, $\mathbf{Z}_{n-1,2,1}$ and $\mathbf{Z}_{n-1,2,2}$, in the FIC approach.

IV. Simulation Studies

In this section, we show the simulated performance of the asynchronous relay network with using the FIC and OFDM approaches. The performance is shown by the end-to-end BER using QPSK symbols. The total power per symbol transmission is fixed as P.

Fig.2 compares the BER performance without FIC and with FIC. The advantage of using the FIC scheme is clear, the BER performance is significantly better than when we do not use the FIC approach. The inter-relay interference considerably corrupts the transmission signal, thereby leading to the performance degradation.

Fig.3 contrasts the performance of asynchronous Alamouti with a two relay network, without IRI, and that of the asynchronous FIC Alamouti with a four relay network with IRI. For the two hop cooperative four relay network, if we use the FIC scheme to completely remove the inter-relay interference, the performance closely matches the asynchronous Alamouti scheme without IRI. However, for the asynchronous Alamouti with two relay networks, every transmission time slot is divided into two sub-slots: firstly, the source transmits to the relay nodes; secondly, the relay node sends the data to the destination. Therefore, the rate and bandwidth efficiency of this scheme is a half of the direct transmission. On the contrary, the later proposed method uses the two group relay nodes in order to retain the successive transmission signal from the source node, so we can approach the full unity data rate when the number of symbols is large.

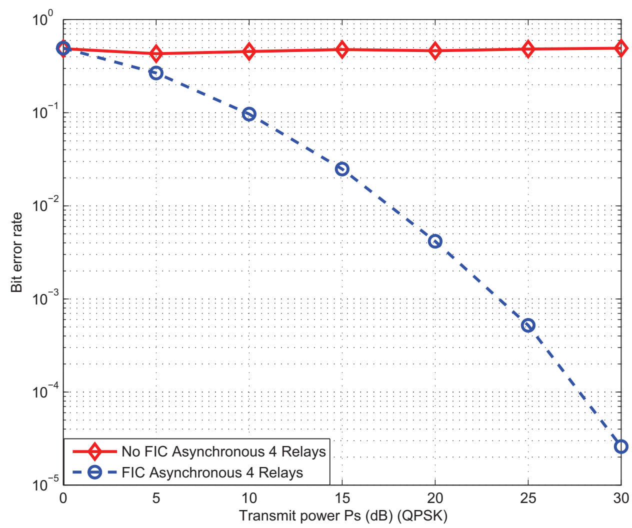

Fig. 2. BER performance for no FIC and FIC approaches

Fig.4 compares the performance of asynchronous Alamouti with using 1/2 rate convolution coding and Viterbi decoding and that of the asynchronous FIC Alamouti without using 1/2 rate convolution coding and Viterbi decoding. From the figure, we can see that, at a BER of 10^{-3}, the coded scheme requires approximately 18 dB while the uncoded scheme requires almost 23 dB. Obviously, the performance of the coded scheme is better than that of uncoded one, which is

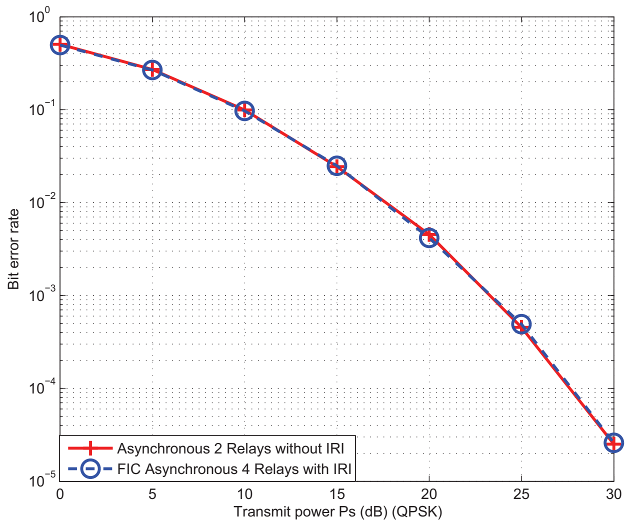

Fig. 3. BER performance of the FIC relay network as compared to a half rate Alamouti relay network

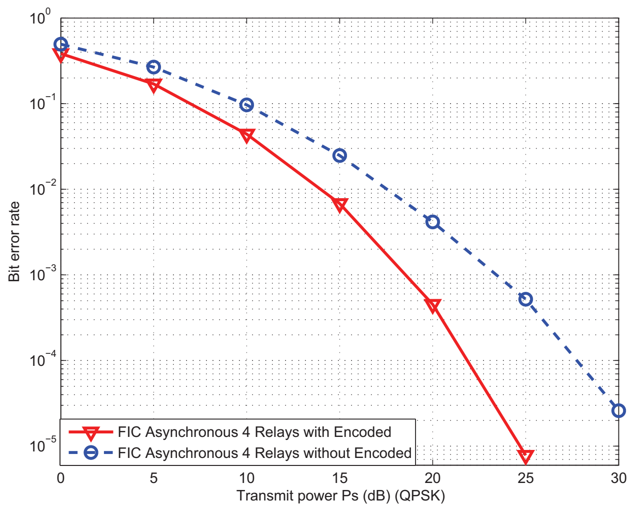

Fig. 4. BER performance for FIC approaches with coded and uncoded

5 dB, because of the coding gain. Therefore, using outer coding in the source and destination can improve end-to-end performance of the cooperative communication scheme.

V. Conclusion

This paper proposed a full interference cancellation with orthogonal frequency-division multiplexing scheme for a four path asynchronous cooperative relay system. We divided these four relays into two groups in order to achieve asymptotically the full data rate, and used a simple Alamouti scheme to obtain full cooperative diversity. We used OFDM and CP at the source to combat timing errors from the relay nodes. Half rate outer convolution encoding and Viterbi decoding were used to improve the coding gain. Finally, the FIC scheme was shown to remove completely the IRI from the received signal at the destination node by using the previous received signal. Therefore, the FIC approach is an attractive scheme to cancel IRI in the multipath cooperative relay system.

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