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CLOSED-LOOP EXTENDED ORTHOGONAL SPACE TIME BLOCK CODING FOR FOUR RELAY NODES UNDER IMPERFECT SYNCHRONIZATION

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ABSTRACT

In future collaborative wireless communication systems with high data rate, interference cancellation is likely to be required in cooperative networks at the symbol level to mitigate synchronization errors. In this paper, we therefore examine closed-loop extended orthogonal space time block coding (CL EO-STBC) for four relay nodes and apply parallel interference cancellation (PIC) detection scheme to mitigate the impact of imperfect synchronization. Simulation results illustrate that the closed-loop EO-STBC scheme under imperfect synchronization can achieve good performance with simple linear processing and outperform previous methods. Moreover, a PIC scheme is shown to be very effective in mitigating impact of imperfect synchronization with low structural and computational complexity.

Index Terms— Closed-loop extended orthogonal space time block coding, linear processing, partial feedback and parallel interference cancellation detection.

I. INTRODUCTION

One of the most common techniques in wireless communication systems with multiple antennas at transmitter is the orthogonal space time block coding STBC which is popularly known as transmit diversity (TD). Furthermore, it is the most significant contributor for achieving transmitter diversity with full data rate, due to its high diversity order and low decoding complexity [1][2]. Due to the cost, size limitation and hardware complexity, it is usually difficult to have multiple antennas in one mobile communication node. In recent years, distributed space time block coding (D-STBC) has become an active and important area of research in wireless communication by sharing antennas of different users since virtual multiple antenna transmitters are generated to improve reliability of transmission and achieve transmitter diversity by applying (STBC) [3][4][5].

In (D-STBC) most widely researchers have focused on the case of two relay nodes using the Alamouti scheme [1] and assumed that cooperative relay nodes are perfectly synchronized at the symbol level, that means all transmitted symbols from all relay nodes reach their destination node at the same time. Unfortunately, this is not a true representation of the real transmission environment, practically the assumption of accurate symbol level synchronization in wireless communication systems (such as ad hoc networks), is difficult

or even impossible to achieve due to the signalling overhead [6][7]. In the imperfect synchronization case between the relay nodes, the channel might become dispersive even under flat fading condition which will damage the orthogonality of (STBC) and can lead to essential performance impairment [8]. Previously, there has been limited work reported regarding the mitigation of interference at the symbol level. The equalization technique was mainly used at the destination node to perform such mitigation [6][9]. Some other techniques were also used to overcome the problem of signal synchronization. One of which proposing a new STBC detection solution based on PIC detection [8][10]. In the case of four relay nodes under imperfect synchronization which was considered in [10], the maximum symbol transmission rate by using complex orthogonal space time block coding was $3/4$ and the PIC detector has moderate computational complexity. However, in this paper we propose a closed-loop EO-STBC [11] under imperfect synchronization with low structural and computational complexity in the PIC detector. We show that closed-loop EO-STBC can achieve full data rate with simple detection, contrary to what was previously achieved in [10].

The paper is organized as follows, Section II describes the proposed closed-loop extended-orthogonal space time block coding under imperfect synchronization. To mitigate the interference at the symbol level at the destination node, the full scheme of parallel interference cancellation (PIC) is introduced in Section III. Simulation results are presented in Section IV. The conclusion follow in Section V.

In the remaining part of this paper, $[\cdot]^T$, $[\cdot]^*$, $|\cdot|$, $\Re\{\cdot\}$ and $\{\cdot\}^H$ denote “transpose”, “conjugate”, “absolute value”, “real part of complex number” and “Hermitian (complex conjugate transpose) of a matrix”, respectively. $CN(0, \sigma^2)$ represent a Gaussian distributed complex number with the standard variance of σ^2 (i.e. $0.5\sigma^2$ per dimension).

II. CLOSED-LOOP EO-STBC UNDER IMPERFECT SYNCHRONIZATION

In this paper the four relays mode closed-loop EO-STBC is depicted in both figures Fig. 1 and Fig. 2, comprising the source node (S), the destination node (D), the four relay nodes (R_1, R_2, R_3, R_4) and the two feedback bits. The scheme comprises two phases. Phase one Fig. 1 for broadcasting and phase two Fig. 2 for relaying.

Phase 1: Node S transmits while nodes (D) and R_m receive. The EO-STBC is encoded at R_m where $m = 1, 2, \dots, 4$ for phase 2, at the S node data symbols are grouped into two symbols $s(i) = [s(1, i), s(2, i)]^T$ and then transmitted to the D and R_m nodes as shown in Fig. 1. The received signal at D node after passing through

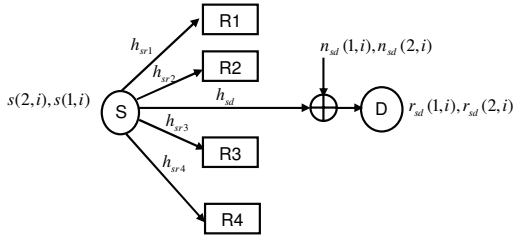


Fig. 1. Phase 1 relay mode with four relay nodes and a direct path

the channels h_{sd} can be expressed as

$$r_{sd}(i) = s(i)h_{sd} + n_{sd}(i) \quad (1)$$

where $h_{sd} \in CN(0, \sigma^2)$ is the channel gain between S and D, $r_{sd}(i) = [r_{sd}(1, i), r_{sd}(2, i)]^T$, $n_{sd}(i) = [n_{sd}(1, i), n_{sd}(2, i)]^T$, where $n_{sd}(j, i) \in CN(0, \sigma_n^2)$ is additive Gaussian noise. The least squares (LS) method can be used to detect which symbols were actually transmitted.

$$\hat{s}_{sd}(j, i) = \arg\{\min_{S_l \in S} |h_{sd}^* r_{sd}(j, i) - |h_{sd}|^2 S_l|^2\} \quad (2)$$

Phase 2: Shown in Fig. 2, at the relay nodes R_m , the data packet is encoded, and then the modulated symbols are fed into the EO-STBC [11]. The relay mode of decode and forward is used in this paper. As such, a sufficient level of cyclic redundancy check (CRC) can be included into the data packet at S node, therefore the relaying will happen if the data packet is correctly detected at R_m . This arrangement is termed “selective relaying” in [12].

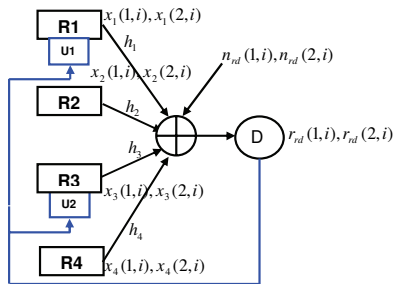


Fig. 2. Phase 2 relay mode with four relay nodes together with feedback scheme to achieve full diversity.

Denoting the encoding data packet at R_m corresponding to $s(i)$ as $x_m(i) = [x_m(1, i), x_m(2, i)]^T$. The EO-STBC matrix which is transmitted by R_m is therefore

$$\begin{bmatrix} x_1(j, i) & x_2(j, i) & x_3(j, i) & x_4(j, i) \end{bmatrix} = \begin{bmatrix} s(1, i) & s(1, i) & s(2, i) & s(2, i) \\ -s^*(2, i) & -s^*(2, i) & s^*(1, i) & s^*(1, i) \end{bmatrix} \quad (3)$$

For achieving full diversity, the data packet from R_1 is multiplied by

$U_1 = (-1)^a$ and R_3 is multiplied by $U_2 = (-1)^b$ as shown in Fig. 2, where $a, b = 0, 1$ prior to transmitting them to D node. In this paper a and b are two feedback parameters which are determined by channel condition, When a or $b = 1$ then U_1 or U_2 equal -1. That means the data packet from R_1 and R_3 in (3) will be phase rotated by 180° before transmitting. Otherwise, the data packet can be directly transmitted. Due to the imperfect synchronization such as different propagation delay, $x_m(i)$ signals will not arrive at the D node in the same time. Which means accurate synchronization is difficult or impossible [7]. As shown in Fig 3 there is normally a timing misalignment of τ_m among the received versions of these signals. Since a rough synchronization is always required. At this point τ_m is smaller than sample period T [7], as shown in Fig 3. It will still cause intersymbol interference (ISI) from neighboring symbols at D node, owing to sampling or matched filtering (whatever pulse shaping is used). As shown in Fig. 3, we assume that the received signal at

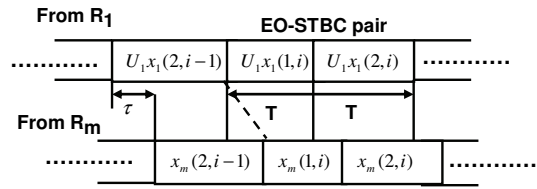


Fig. 3. Imperfect synchronization at the D node the received signal at D node is the superposition of four symbol.

the D node is perfectly synchronized to R_1 , ($\tau_1 = 0$) therefore, the received signals $r_{rd}(1, i)$ and $r_{rd}(2, i)$ at the D node in the two independent time intervals are expressed as follows

$$\begin{aligned} r_{rd}(1, i) &= U_1 h_1(0) x_1(1, i) + h_2(0) x_2(1, i) + U_2 h_3(0) \\ &\quad x_3(1, i) + h_4(0) x_4(1, i) + h_2(-1) x_2(2, i - 1) \\ &\quad + U_2 h_3(-1) x_3(2, i - 1) + h_4(-1) x_4(2, i - 1) \\ &\quad + n_{rd}(1, i) \end{aligned} \quad (4)$$

$$\begin{aligned} r_{rd}(2, i) &= U_1 h_1(0) x_1(2, i) + h_2(0) x_2(2, i) + U_2 h_3(0) \\ &\quad x_3(2, i) + h_4(0) x_4(2, i) + h_2(-1) x_2(1, i) \\ &\quad + U_2 h_3(-1) x_3(1, i) + h_4(-1) x_4(1, i) \\ &\quad + n_{rd}(2, i) \end{aligned} \quad (5)$$

where $n_{rd}(j, i) \in CN(0, \sigma_n^2)$ is additive Gaussian noise and $h_m(l)$ is the channel gains between R_m and D node under imperfect inter node synchronization and assumed to be block Rayleigh fading from packet to packet, (note that $h_1(0) = h_1$) i.e $h_m \in CN(0, \sigma_r^2)$. For fair comparison with non-relay scheme, all relay nodes transmit at 1/4 power i.e $\sigma_r^2 = \sigma_s^2/4$. Due to imperfect synchronization $h_m(-1)$ reflects the inter symbol interference from previous symbol. The relative strength of $h_m(-1)$ will be expressed by ratio as follows [8][10].

$$\beta_m = |h_m(-1)|^2 / |h_m(0)|^2 \quad (6)$$

where β_m is used to denote how the level of imperfect synchronization. Similarly, the equation $|h_m(-1)|^2 + |h_m(0)|^2 \leq |h_m|^2$ was used and we normally have $\beta_m = 0$ for $\tau_m = 0$, and $\beta_m = 1$ (i.e. 0 dB) for $\tau_m = 0.5T$. Substituting (3) into (4) and (5), the received

signals $r_{rd}(1, i)$ and $r_{rd}(2, i)$, conjugated for convenience at two independent time intervals are expressed as follows

$$\mathbf{r}(i) = \mathbf{H}s(i) + \mathbf{I}(i) + \mathbf{n}_{rd}(i) \quad (7)$$

where

$$\mathbf{r}(i) = [r_{rd}(1, i), r_{rd}^*(2, i)]^T, \mathbf{n}_{rd}(i) = [n_{rd}(1, i), n_{rd}^*(2, i)]^T,$$

$$\mathbf{H} = \begin{bmatrix} U_1 h_1(0) + h_2(0) & U_2 h_3(0) + h_4(0) \\ U_2^* h_3^*(0) + h_4^*(0) & -U_1^* h_1^*(0) - h_2^*(0) \end{bmatrix},$$

and

$$\mathbf{I}(1, i) = h_2(-1)s^*(2, i-1) + (U_2 h_3(-1)h_4(-1))s^*(1, i-1)$$

$$\mathbf{I}^*(2, i) = h_2^*(-1)s^*(1, i) + (U_2^* h_3^*(-1)h_4^*(-1))s^*(2, i)$$

from (7), the conventional closed-loop EO-STBC detection can be carried out via the following standard two step procedure assuming perfect channel state information at D node. Therefore, the detection vector $\mathbf{y}(i) = [y(1, i), y(2, i)]^T$ with the receive vector $\mathbf{r}(i) = [r_{rd}(1, i), r_{rd}^*(2, i)]^T$ can be calculated

STEP 1: linear transform

$$\mathbf{y}(i) = [y(1, i), y(2, i)]^T = \mathbf{H}^H \mathbf{r}(i)$$

$$= \underbrace{(|U_1|^2 |h_1(0)|^2 + |h_2(0)|^2 + |U_2|^2 |h_3(0)|^2 + |h_4(0)|^2)}_{g_c}$$

$$+ \underbrace{2\Re(U_1 h_1(0)h_2^*(0)) + 2\Re(U_2 h_3(0)h_4^*(0))}_{g_f} s(i)$$

$$+ \mathbf{H}^H \mathbf{I}(i) + \mathbf{v}(i) \quad (8)$$

where $\mathbf{v}(i) = \mathbf{H}^H \mathbf{n}_{rd}(i)$ is a noise component. Since $|U_1|^2 = |U_2|^2 = 1$ then the channel gain g is expressed as follows

$$g = \sum_{i=1}^4 \underbrace{|h_i(0)|^2}_{g_c} + \underbrace{2\Re(h_1(0)h_2^*(0) + h_3(0)h_4^*(0))}_{g_f} \quad (9)$$

where g_c is the conventional channel gain for four relay nodes and g_f is the feedback performance gain. The g_f changes with the defined value of U_1 and U_2 as mention above. According to the above analysis, the two-bit feedback can be designed as shown in [11], in which each element of feedback performance gain g_f in (9) must be nonnegative. The two-bit feedback has been chosen to maximize the value of g_f in (8), which leads to a larger received SNR, which shows the closed-loop EO-STBC scheme achieves the better performance rather than the pervious work in [10] under imperfect synchronization. On the other hand, closed-loop EO-STBC can be used for more than four relay node under imperfect synchronization. However, more feedback bit needs for large relay nodes.

STEP 2: Least squares (LS) detection

$$\hat{s}_{rd}(j, i) = \arg\{\min_{S_i \in S} |y(j, i) - |g|^2 S_i|^2\} \quad (10)$$

The above procedure can suffer from significant detection error, because of the $\mathbf{H}^H \mathbf{I}(i)$ component in (8) which will damage the orthogonality of closed-loop EO-STBC. However, this procedure can give good performance gain when the $h_m(-1) = 0$ (i.e. $\tau = 0$ in case of perfect synchronization), that's why the performance of conventional closed-loop EO-STBC detector impairment under imperfect synchronization.

III. PIC BASED DETECTION

The principle of parallel interference cancelation is applied to remove the impact of imperfect synchronization of the interference component $\mathbf{I}(i)$ from (7), assuming perfect channel state information at D node. Whether the interference component $\mathbf{I}(i)$ in (7) is removed, that means the PIC detection would achieve maximum likelihood due to the closed-loop EO-STBC structure. Previous, PIC detection is applied to a co-located STBC system [13]. Since that $x_m(2, i-1)$ in (4) and (5) is already known if the detection process has been initialized properly, $I(1, i)$ can be removed during the initialization stage. The PIC iteration process can then be used to mitigate the impact of $\mathbf{I}(i)$ in (7) as follows

Initialization : 1-set iteration number $K=0$

2- From the received signal $\mathbf{r}(i)$ in (7) calculate

$$\hat{\mathbf{r}}^{(0)}(i) = [\mathbf{r}_{rd}(1, i) - \mathbf{I}(1, i), \mathbf{r}_{rd}^*(2, i)]^T$$

3- Because of the poor performance of the conventional detector, the (DT) detection result in (2) has been used to initialize $s^{(0)}(i)$:

$$s^{(0)}(i) = [s^{(0)}(1, i), s^{(0)}(2, i)]^T = [\hat{s}_{sd}^{(0)}(1, i), \hat{s}_{sd}^{(0)}(2, i)]^T$$

4- Set the iteration number $K=1, 2, \dots, N$

5- Remove more ISI in (5) by calculating

$$\hat{\mathbf{r}}^{(K)}(i) = [\mathbf{r}_{rd}(1, i) - \mathbf{I}(1, i), \mathbf{r}_{rd}^*(2, i) - I^{*(K-1)}(2, i)]^T$$

where

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

$$+ (U_2^* h_3^*(-1) + h_4^*(-1))[\mathbf{s}^{(K-1)}(2, i)]^* \quad (11)$$

6- Substitute $\mathbf{r}(i)$ in (8) with $\hat{\mathbf{r}}^{(K)}(i)$ to obtain $\mathbf{y}^{(K)}(i)$, and then apply the LS detection to $\mathbf{y}^{(K)}(i)$ to obtain the detection result of $\hat{\mathbf{s}}^{(K)}(j, i)$.

7- Repeat the process from point 4 until $K \leq N$

IV. SIMULATION RESULTS

Simulation results of our proposed closed-loop EO-STBC under imperfect synchronization is given in this section. All simulations which have performed in this paper are uncoded. The bit error rate (BER) performance against signal to noise ratio (SNR) was simulated by using 8PSK gray mapping scheme in [10]. The SNR is defined as $SNR = \sigma_s^2 / \sigma_n^2$ and all relay nodes transmit at 1/4 power. A comparison was made between the BER performance of the proposed closed-loop EO-STBC with previous work in [10] under perfect synchronization as shown in Fig 4. In Fig. 4 and 5, the impact level of synchronization is shown by changing the value of β_m , that means the time delay between R_1 and the other relays is changed. Fig. 4, shows the result of conventional detector under different β_m value also the BER for (DT), closed-loop EO-STBC and previous work in [10] under perfect synchronization are included as reference, Fig. 4, shows the conventional detector is not effective to synchronization error even under small time misalignments $\beta_m = -6$. On the other hand, the PIC scheme is very effective in mitigating synchronization error even under large time misalignments $\beta_m = 0$ as shown in Fig (5) when the number of PIC iterations $K=3$. Fig. 6, illustrates the BER of PIC iterations for $K=0, 1, 2, 3$ and $\beta_m = -3$, the figure shows

the conventional detector dose not deliver the performances gain under imperfect synchronization, while the PIC scheme is very effective to mitigate the impact of imperfect synchronization, the second and third iteration deliver the performance gain.

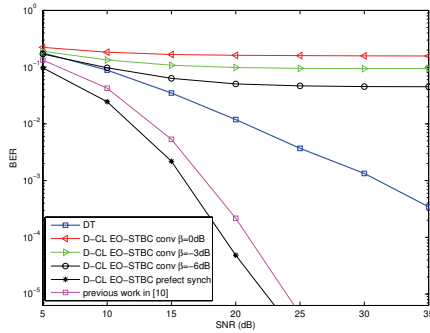


Fig. 4. The BER performance of conventional detection under different β_m values.

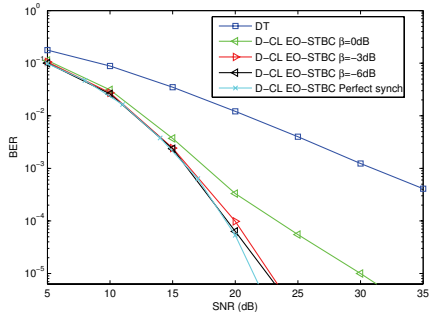


Fig. 5. The BER performance of PIC detection under different β_m values.

V. CONCLUSION

This paper presented a simple closed-loop EO-STBC for system with four relay nodes under imperfect synchronization. To suppress the interference to the system performance, we employ the PIC detection scheme, which can effectively remove the interference caused by imperfect synchronization. Simulation results demonstrated that the proposed closed-loop EO-STBC can outperform previous work and achieve higher diversity order. Furthermore, the conventional closed-loop EO-STBC detector is very sensitive in mitigating synchronization error rather than PIC detector. Meanwhile, the proposed scheme is relatively low structural and computational complexity from previous work. Finally the received signals during phase two can be combining with received signals during phase one (DT) to deliver significant performance gain.

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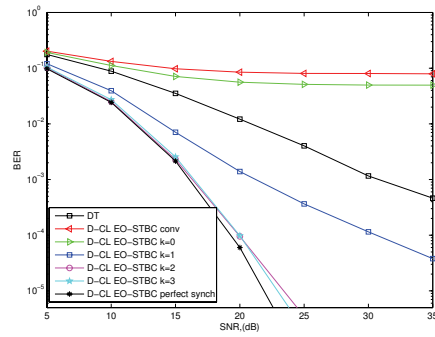


Fig. 6. The BER performance of PIC detection for different K number of iterations.

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