The Asynchronous Cooperative Amplify-and-Forward Relay Network with Partial Feedback to Improve the System Performance

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Abstract. In this paper, a new near-optimum detection (NOD) scheme is combined with partial feedback technique for two dual-antenna relay nodes in the amplify-and-forward (AF) asynchronous cooperative relay network. The application of partial feedback in the proposed scheme not only offers to reduce a cooperative relaying process due to not using distributed close loop extended orthogonal space-time block code (DCL EO-STBC) encoder, but also improves the end-to-end signal noise ratio (SNR). Moreover, a near-optimum detection (NOD) scheme is used at the destination to remove completely the interference components induced by inter-symbol interference (ISI) among the relay nodes. The analysis and simulation results demonstrate that the performance of the proposed scheme outperforms the previous feedback scheme in both the perfect synchronization and imperfect synchronization assumption cases.

Keywords: Partial feedback · Near-optimum detection · Inter-symbol interference · Distributed close loop extended orthogonal space-time block code · Asynchronous cooperative relay

1 Introduction

Communicating via multiple cooperative relay nodes helps to combat the detrimental effects of fading in wireless channels by providing additional diversity/ reliability to the system. This diversity arises because the channel fading gain varies depending on the location of the relay node and thus well separated multiple relay nodes can bring in independent channel fading gains and hence more diversity or protection to the transmitted information [1]. However, the assumption that the cooperative relay nodes transmit the corresponding symbols to the destination node at the same time in a perfect synchronized manner is difficult or impossible. Thus, the bit error rate (BER) performance significantly degrades due to the inter-symbol interference (ISI) in the cooperative relay transmissions [2–8].

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The most commonly utilized strategies with various cooperative relaying protocols are either amplify and forward (AF) or decode and forward (DF) [9]. In [2] and [4], asynchronous cooperative relay networks are demonstrated using distributed close loop extended orthogonal space-time block code (DCL EO-STBC) and distributed space-time block code (D-STBC) with near-optimum detection (NOD) at the destination, respectively. These proposed schemes overcame this lack of the imperfect synchronization by introducing ISI components with DF strategy, which leads to high process at relay nodes. Another example of the DF protocol, in [8], Elazreg et al. propose using distributed close loop quasi orthogonal space-time block code (DCL QO-STBC) and Sub-optimum detection. Whereas in [1] and [3] authors considered a simple cooperative relaying strategy with DCL EO-STBC and DCL QO-STBC, respectively. In this cooperative method, each relay node receives a noisy version of the signal transmitted by the source node, and amplifies and retransmits this noisy version to the destination node. The transmission strategy calls AF protocol, which does not need channel information at the relay nodes, but full channel information from the source node to the relay nodes and from the relay nodes to the destination node are required at the destination node. In addition, the AF strategy does not perform any decoding operation at the relay node. Therefore, the AF protocol is a best cooperative relaying process in the case of relay nodes require low operation and saving power such as Ad hoc wireless network or sensor network [10].

All above designs can effectively eliminate ISI components with AF or DF protocol and exploit the diversity gain and transmission rate. But, the process complexity of relay node is still high because the relay nodes need to use a DCL EO-STBC (DCL QO-STBC) encoder.

This paper proposes a new AF asynchronous cooperative relay network with partial feedback. The AF strategy of proposed scheme reduces a cooperative relaying process due to not using DCL EO-STBC encoder in comparison with the previous cooperative AF relay network [1]. Moreover, the proposed scheme not only offers to achieve the maximum signal noise rate (SNR), but also can completely eliminate ISI components with implementing near-optimum detection at the destination.

The remainder of this paper is organized as follows: In the Sect. 2, the proposed AF asynchronous cooperative relay network with partial feedback is described; The detection of interference cancellation is presented and analyzed in the Sect. 3; Simulation results and performance comparisons are presented in Sect. 4; Finally, Sect. 5 summarizes this paper.

In the remaining part of this paper, $[.]^T$, $[.]^*$ and $\|.\|^2$ denote transpose, complex conjugate, and Frobenius operation, respectively; $\Re$ and $\Im$ present to take the real and imaginary part of the complex variable, respectively; $\mathbb{E}[.]$ represents an expectational operation; and $\mathcal{A}$ indicates the signal constellation.

2 The Proposed AF Asynchronous Cooperative Relay Network with Partial Feedback

In this paper, the AF asynchronous cooperative relay network with partial feedback is considered as shown in Fig. 1. This model consists of the single-antenna source node and destination node, and two dual-antenna relay nodes. The direct transmission link from the source node to the destination node is ignored due to the effect of path loss and the limited transmitted power. Let f_{ik} denotes the channel coefficient from the source node to *i-th* the antenna of the *k-th* relay node and g_{ik} is the channel coefficient from the *i-th* antenna of the *k-th* relay node to the destination node. We also assume that all channel coefficients f_{ik} and g_{ik} (for i, $k = \overline{1,2}$) are kept constant during two symbol interval and varied randomly in the next two symbol interval (i.e. a flat-static channel). The noise terms of both relay and destination node are assumed the additive complex Gaussian noises with the distribution $\mathcal{CN}(0,1)$. It is assumed that feedback link has no feedback error and no delay. The total transmitted power utilized for the transmission of one symbol is fixed as P(dB). We adopt the optimal power allocation presented in [11] as follows:

$$P_1 = \frac{P}{2},\ P_2 = \frac{P}{4}, \tag{B.1}$$

where, $P_1,\ P_2$ are the transmit power at the source and the each relay node, respectively.

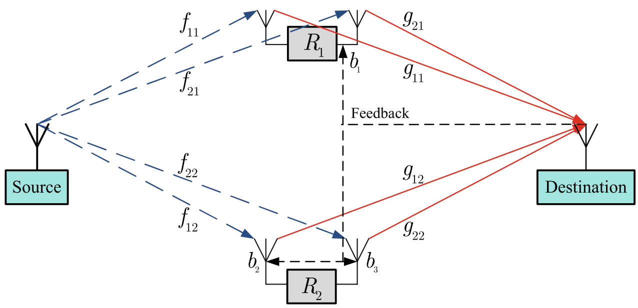


Fig. 1. The AF asynchronous cooperative relay network with partial feedback.

In the first phase, the source node broadcasts the sequent modulated symbols $s(n)$ to every relay node in one symbol period. So, the received symbol at the *i-th* antenna of the *k-th* relay node is presented as:

$$r_{ik}(n) = \sqrt{P_1} f_{ik} s(n) + z_{ik}(n), \tag{B.2}$$

where, $z_{ik}(n)$ is noise at the *i-th* antenna of the *k-th* relay node.

In the second phase, this paper applies a partial feedback in [12] to achieve the array gain for the AF asynchronous cooperative relay network. It is assumed that b_1, b_2 and b_3 are the feedback bits from the destination node to the relay nodes. Firstly, the received symbols in (B.2) are multiplied with feedback bits which is equivalent to phase rotations of the corresponding channel coefficients. This is important to improve end-to-end SNR of the proposed scheme. The transmitted symbol vector for two dual-antenna relays is presented as in (B.3):

$$E_B = [r_{11}(n)\ b_1 r_{21}(n)\ b_2 r_{21}(n)\ b_3 r_{22}(n)] \tag{B.3}$$

where, b_i $(i = 1, 2, 3)$ is equal to 1 or -1 depending on the channel static information.

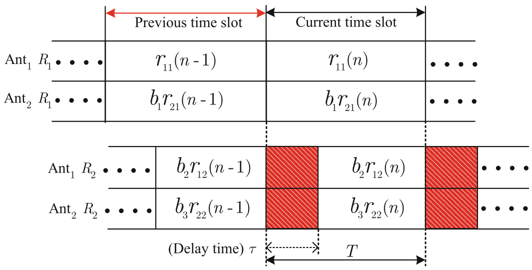


Fig. 2. The effect of imperfect synchronization in the asynchronous cooperative relay network.

As the previous discussions, the propagation delays of received signals from the distinct relay node are not the same length due to the different distances between the relay nodes and the destination node. Without loss of generality, it is assumed that the links of the between both antennas of the first relay node (denotes R_1) and the destination are synchronized perfectly. But, the links of the between both antennas of the second relay node (denotes R_2) and the destination are synchronized imperfectly. So that is $\tau \neq 0$ as shown in Fig. 2. The received signal at the destination node are presented as following:

$$\begin{aligned} y(n) = &\sqrt{\frac{P_2}{(P_1+1)}}\left[r_{11}(n)g_{11} + b_1 r_{21}(n)g_{21} + b_2 r_{12}(n)g_{12} + b_3 r_{22}(n)g_{22}\right] \\ &+ \sqrt{\frac{P_2}{(P_1+1)}}\left[b_2 r_{12}(n-1)g_{12}(-1) + b_3 r_{22}(n-1)g_{22}(-1)\right] + v(n) \end{aligned} \tag{B.4}$$

$$= \sqrt{\frac{P_1 P_2}{(P_1+1)}} h s(n) + I_{\text{int}}(n) + w(n), \tag{B.5}$$

where, $h = f_{11}g_{11} + b_1 f_{21}g_{21} + b_2 f_{12}g_{12} + b_3 f_{22}g_{22}$ is the equivalent channel gain. $I_{\text{int}}(n)$ is the interference term from both antennas of the second relay node due to the effect of asynchronous phenomenon and calculates as following:

$$I_{\text{int}}(n) = \sqrt{\frac{P_1 P_2}{(P_1+1)}}\left\{b_2 f_{11}g_{12}(-1) + b_3 f_{22}g_{22}(-1)\right\} s(n-1). \tag{B.6}$$

$w(n)$ is the equivalent noise at destination and it is presented as:

$$w(n) = \sqrt{\frac{P_2}{(P_1+1)}}\left(g_{11}z_{11}(n) + b_1 g_{21}z_{21}(n) + +b_2 g_{12}z_{12}(n) + b_3 g_{22}z_{22}(n)\right) + v(n). \quad \text{(B.7)}$$

$v(n)$ is noise at the destination node. As shown in Fig. 2, $g_{i2}(-1)$ $(i = 1, 2)$ is the channel gain between the antenna of R_2 and the destination under imperfect synchronization. The $g_{i2}(-1)$ is related with g_{i2} as following [1]:

$$\beta = |g_{i2}(-1)|^2 / |g_{i2}|^2; \quad i = 1, 2 \quad \text{(B.8)}$$

This paper adopted with $\beta = 0$ for $\tau = 0$ and $\beta = 1$ (i.e. 0 dB) for $\tau = 0.5T$ [1]. Note that, the factor $\sqrt{P_2/(P_1+1)}$ in the Eq. (B.5) is ensured the average transmission power at the each relay node is P_2. It is assumed that the destination node knows completely all the channel coefficients f_{ik} and g_{ik}. Its knowledge of the channels can be obtained by sending training signals. Then, the conventional detection procedure of the proposed scheme can be carried out via the Least Square (LS) method as follows:

$$y(n) = h^* r(n) = \sqrt{\frac{P_1 P_2}{(P_1+1)}}\lambda s(n) + h^* I_{\text{int}}(n) + h^* w(n) \quad \text{(B.9)}$$

$$\tilde{s}(n) = \arg\min_{s_m \in \mathcal{A}} \left| y(n) - \sqrt{\frac{P_1 P_2}{(P_1+1)}}\lambda s_m \right|^2, \quad \text{(B.10)}$$

where, $\mathcal{A}$ denotes the constellation and $\lambda = h^* h = \alpha_B + \beta_B$ is total performance gain as following:

$$\alpha_B = |f_{11}g_{11}|^2 + |f_{21}g_{21}|^2 + |f_{12}g_{12}|^2 + |f_{22}g_{22}|^2; \quad \text{(B.11)}$$

$$\begin{aligned}\beta_B = {} & 2b_1 \Re\left(f_{11}g_{11}f_{21}^* g_{21}^*\right) + 2b_2 \Re\left(f_{11}g_{11}f_{12}^* g_{12}^* + b_1 f_{21}g_{21}f_{12}^* g_{12}^*\right) \\ & + 2b_3 \Re\left(f_{11}g_{11}f_{22}^* g_{22}^* + b_1 f_{21}g_{21}f_{22}^* g_{22}^* + b_2 f_{12}g_{12}f_{22}^* g_{22}^*\right).\end{aligned} \quad \text{(B.12)}$$

The proposed scheme gets the conventional diversity gain α_B and the array performance gain β_B. It is clear that $\alpha_B \geq 0$ is always true. The application of the partial feedback idea in [12], the additional array gain can achieved if the feedback bits are calculated as following Table 1.

Remarks

- The additional array gain of the proposed scheme β_B in (B.12) is bigger than the performance array gain of the DCL EO-STBC scheme λ_f in [1] when the partial phase feedback bits are calculated as Table 1. In consequence, the signal noise ratio (SNR) of the proposed scheme is better than the DCL EO-STBC scheme.
- It is clear that the process of relay nodes is very simple due to relay nodes do not use neither the DF protocol or the DCL EO-STBC encoder.
- The Eq. (B.9) shows that the performance of new scheme will damage because there is an ISI component $I_{\text{int}}(n)$ in the received signal unless the $g_{i2}(-1)$ gets 0 (i.e. $\tau = 0$, the case of perfect synchronization) or the ISI component is removed.

Table 1. Calculation of the feedback bits.

Step 1: b_1	$= 1 \quad if\ \Re\left(f_{11}g_{11}f_{21}^*g_{21}^*\right) \geq 0$
	$= -1 \quad if\ \Re\left(f_{11}g_{11}f_{21}^*g_{21}^*\right) < 0$
Step 2: b_2	$= 1 \quad if\ \Re\left(f_{11}g_{11}f_{12}^*g_{12}^* + b_1 f_{21}g_{21}f_{12}^*g_{12}^*\right) \geq 0$
	$= -1 \quad if\ \Re\left(f_{11}g_{11}f_{12}^*g_{12}^* + b_1 f_{21}g_{21}f_{12}^*g_{12}^*\right) < 0$
Step 3: b_3	$= 1 \quad if\ \Re\left(f_{11}g_{11}f_{22}^*g_{22}^* + b_1 f_{21}g_{21}f_{22}^*g_{22}^* + b_2 f_{12}g_{12}f_{22}^*g_{22}^*\right) \geq 0$
	$= -1 \quad if\ \Re\left(f_{11}g_{11}f_{22}^*g_{22}^* + b_1 f_{21}g_{21}f_{22}^*g_{22}^* + b_2 f_{12}g_{12}f_{22}^*g_{22}^*\right) < 0$

3 Near-Optimum Detection for the Proposed Scheme

As the previous mention in Sect. 2, the key to mitigate the above impact of imperfect synchronization is to remove the ISI component of $I_{\text{int}}(n)$ in (B.5). Fortunately, the Fig. 2 and Eq. (B.6) show that there are only two previous ISI components in received signals at the destination. Therefore, the NOD scheme is used at the destination to remove completely the ISI components $I_{\text{int}}(n)$ in the Eq. (B.5) before applying the matched filter in (B.9). In fact, $s(n-1)$ is already known if the detection process has been initialized properly [1]. So, the interference components $I_{\text{int}}(n) = \sqrt{P_1P_2/(P_1+1)}\,\{b_2 f_{11}g_{12}(-1) + b_3 f_{22}g_{22}(-1)\}\, s(n-1)$ in (B.5) can be eliminated completely as the below procedure:

Step 1: Remove the ISI component $I_{\text{int}}(n)$ in (B.5)

$$y'(n) = y(n) - I_{\text{int}}(n) = \sqrt{\frac{P_1P_2}{(P_1+1)}}hs(n) + w(n), \tag{B.13}$$

Step 2: Linear transform

$$y''(n) = h^*y'(n) = \sqrt{\frac{P_1P_2}{(P_1+1)}}\lambda s(n) + h^*w(n), \tag{B.14}$$

Step 3: Application the LS (Least Square):

$$\tilde{s}(n) = \underset{s_m \in \mathcal{A}}{\arg\min}\left|y''(n) - \sqrt{\frac{P_1P_2}{(P_1+1)}}\lambda s_m\right|^2. \tag{B.15}$$

As above analysis, the ISI component in the Eq. (B.13) is removed if the initialized signal $s(n-1)$ has no decision feedback error, then the above procedure is optimum in terms of maximum likelihood which calls Near-Optimum Detection (NOD).

Remarks

- It is clear that the above procedure can remove completely the ISI component which cause the different propagation delays in the asynchronous cooperative relay network.

– The above procedure does not rely on the detection results of the transmission link between the source node and destination, so the detection complexity of the proposed scheme is significantly reduced as compared with Sub-optimum detection [8].

4 Simulation Results

In this section, simulation results with the Monte-Carlo method are shown and demonstrated for our previous analysis. All schemes use QPSK modulation and have the same total transmitted power. The fading is assumed quasi-static fading which keeps a constant within a frame and changes independently from frame-to-frame. The level of imperfect synchronization (i.e. τ the time delays between both antennas of the second relay node and the destination node) is changed by varying the value of β (dB).

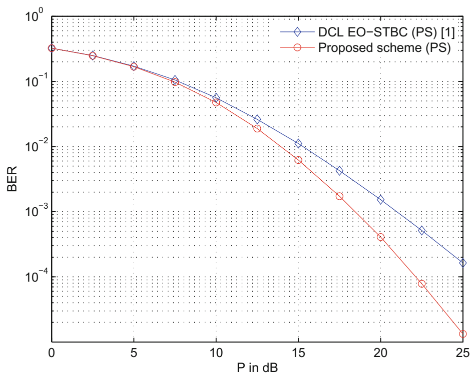
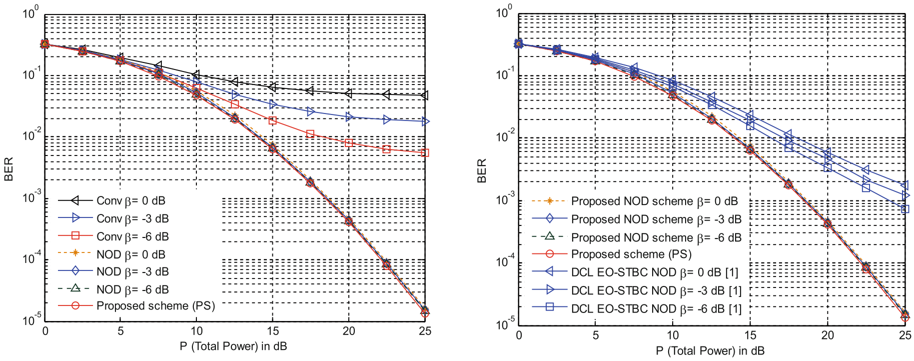


Fig. 3. BER performance comparison of proposed scheme and DCL EO-STBC scheme [1] in case perfect synchronization.

Figure 3 shows the comparison results of BER performance the proposed scheme and DCL EO-STBC scheme [1] in case perfect synchronization (PS). It confirms that the proposed scheme is better than DCL EO-STBC scheme because the SNR of the proposed scheme is improved when the simple partial feedback is applied as analysis in Sect. 2. For example, the proposed scheme just requires approximately the source power 18.5 dB to achieve a BER of 10^{-3}, while the DCL EO-STBC scheme requires 21 dB. It notices that two schemes have same hardware requirement.

The BER performances of the proposed scheme utilized NOD or conventional (Conv) detection show in Fig. 4(a) under the different levels of imperfect synchronization ($\beta = 0,\ -3\ and - 6\,(\text{dB})$). Figure 4(a) confirms that the proposed scheme with application of NOD has good performance because the ISI components can completely remove before using the LS detector while Conv detector



a) NOD detector vs Conv detector. b) The proposed scheme vs the DCL EO-STBC scheme [1].

Fig. 4. The comparison of BER performance proposed scheme.

fails even under small β values (or slight imperfect synchronization). Specially, the BER total system performance of the proposed NOD scheme can be close its BER in the perfect synchronization case. Therefore, the new NOD scheme can fight extremely asynchronous phenomenon.

Comparisons of the BER performance between the proposed scheme and the DCL EO-STBC scheme [1] with the same configuration model and NOD detector are shown in Fig. 4(b). As seen in the simulation results, it is clear that the degradation of BER performance of DCL EO-STBC scheme is very fast when increasing factor β (i.e. more loss of synchronization). Whereas BER performance of proposed scheme degrades very slowly in the asynchronous channel conditions.

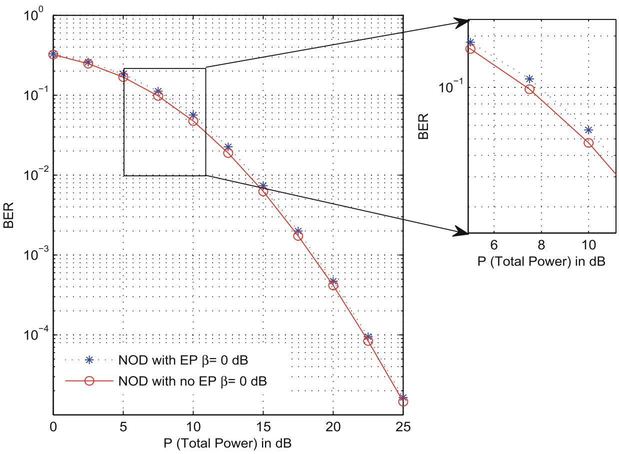


Fig. 5. The impact of error propagation (EP) on the BER performance.

To examine the effect of decision feedback errors, BER performance of the proposed NOD scheme is carried out (i) with error propagation (EP, i.e. $s(n-1)$ gets the value of previous detection or natural propagation of any feedback errors), and (ii) with no EP (i.e. using the previous true symbol) for ISI removal. The BER performance of comparison shows as Fig. 5 with large level of imperfect synchronization $\beta = 0\,\text{dB}$. The Fig. 5 shows that the impact of error propagation of the near-optimum detector is very minor.

5 Conclusion

In this paper, we have proposed a new AF asynchronous cooperative relay network with partial feedback. The proposed scheme achieves maximum SNR by using the partial feedback while reduces the AF cooperative relaying process without utilized DCL EO-STBC encoder at relay nodes. Analysis and simulation results confirmed that the application of NOD at destination can completely remove the ISI components and overcome this lack of asynchronous cooperative relay network. In practice, the 3 feedback bits of the new scheme requirement are available in the 3G system with supporting the 1.5 kbps feedback link. Therefore, this scheme is fully compatible with cooperative relay networks such as wireless ad hoc or sensor networks in asynchronous channel conditions.

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