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Iterative Spatial Demapping for Simultaneous Full Data Exchange in Three-way Relaying Channels

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Iterative Spatial Demapping for Simultaneous Full Data Exchange in Three-way Relaying Systems

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Abstract—This TD presents an iterative spatial demapping (ISM) for simultaneous full data exchange in three-way relaying systems where there is no direct link between the users. Based on a priori knowledge provided by the decoders, ISM demapper makes it possible for the three users to exchange information simultaneously within only two phase transmissions by help of a relay. In the first phase, each user transmit simultaneously, while at the second phase, the relay amplify-and-forward the received composite signals to each user. The performances are evaluated by computer simulations in additive white Gaussian noise (AWGN) and frequency-flat Rayleigh fading channels. Bit-error-rate (BER) performance results show that clear turbo cliff is achieved at each user’s transmit power of 2.38 dB in AWGN channel (for each user). Extrinsic information transfer (EXIT) chart-based analysis are also presented to evaluate the convergence property of the iterative decoding algorithm. The proposed structure is simple since each transmitter consists of 2-state rate-1 doped accumulator as an inner encoder and short memory convolutional code (CC) as the outer encoder. Since the proposed technique is also spectrally efficient (because only two phase transmission is used for three users), its application application includes future conferencing multi-way relaying systems where energy and computational complexity are of significant important.

I. INTRODUCTION

Development of portable wireless devices enable conference calls in which each user in a group is interested in sending and receiving data to and from all members in the groups is needed, for example, by emergency team in a disaster site. The similar situation happens between satellite and users on the earth, where the coverage and quality of the direct link is limited from the satellite to the users. To increase spectrum efficiency and extend the coverage, a practical solution is to introduce relay terminals. This terminal is critical information especially when each user does not have direct link to other users or the satellites.

Studies on cooperative transmission for multiple users with the help of a relay have been presented, for example, in [1] where it is stated that feedback is still beneficial in multiuser multiway relay channel and its output is common for each user. Ref. [2] studies the theoretical analysis where the relay has its own message for each user, while in [3] the practical iterative decoding technique is proposed by assuming that the direct link between the users is available. In [4], three dimensional network coding scheme is proposed for three-way relay channels by considering fairness among the users.

Fig. 1. Full data exchange in three-way relay systems with only two phase transmissions: (1) Phase 1: MAC channel (dashed lines), (2) Phase 2: Broadcast Channel (solid lines)

Many literatures assume that each user transmit their messages in different time slots, where the scheduling and multiple time slots are needed to avoid multiple access interference (MAI) [5]. With the insight from [6], in this work, we focus on full data exchange in three-way relay channels where all users simultaneously transmit their information to the relay (Phase 1) and the relay, broadcast their message as common output of the three-way relay channel (Phase 2).

II. SYSTEM MODEL

We focus on single carrier signalling transmission. Fig. 2 shows the system model considered in this TD. During Phase 1, each user transmits message $s_i, i \in \{1, 2, 3\}$ simultaneously as indicated by dashed line. The relay (R) amplify-and-forward (AF) the message from each user and broadcast $s_R$ to all users during Phase 2 as indicated by solid line.

In this TD, we assume the messages $s_1, s_2, s_3$ are all in binary phase shift keying (BPSK) modulated symbol with $\mathbb{E}[s_1] = \mathbb{E}[s_2] = \mathbb{E}[s_3] = 1$. The channels coefficient between users and relay, $h_1, h_2, h_3$, are assumed to be known to the receiver only in each phase but the phase difference $\theta = \angle(h_1, h_i)$ is assumed to be unknown, where $i \in \{1, 2, 3\}$ and $i \neq i$.

The received signal at the relay is expressed as

$$y_R = h_1s_1 + h_2s_2 + h_3s_3 + \sigma^2,$$

(1)
where \( \sigma_i^2 \) is the noise variance at the relay. The relay amplify-and-forward the received signal \( y_R \) to each user with amplification/scaling factor \( G \) as

\[
y_i = G y_R + \sigma_i^2,
\]

with \( y_i \) and \( \sigma_i^2 \) being the received signal and noise variance at the \( i \)-th destination, \( i \in \{1, 2, 3\} \). Each user knows \( G \) and possible to subtract from its own signal so that the received signal at each \( i \)-th user is expressed as

\[
y_i = G y_R - G s_i + \sigma_i^2,
\]

(3)

By assuming that each user transmit with the same power \( P_1 = P_2 = P_3 = P \), \( \sigma_i^2 = \sigma_3^2 = \sigma_3^2 = 1 \), and power of relay does not exceed \( P_r \), we can re-express the scaling factor \( G \) as

\[
G = \sqrt{\frac{P_r}{y_R}} = \sqrt{\frac{P_r}{3P + 1}}
\]

(4)

(5)

with the signal-to-noise power ratio (SNR) \( \gamma \) being

\[
\gamma = \frac{G^2 (2P)}{(G^2 + 1)} = \frac{2PP_r}{3(P + 1)}
\]

(6)

### III. Proposed Decoding Strategy

#### A. Source

Our proposed decoding strategy for three-way relay systems is shown in Fig. 2. Three sources \( b_1, b_2, \) and \( b_3 \) are transmitted from three separated single antenna simultaneously. The bitstream \( b_i \) is convolutionally encoded using \( C_i \), interleaved by \( \Pi_i \), doped accumulated, and BPSK-modulated to produce BPSK symbol \( s_i \).

The rate-1 doped accumulator (D-ACC) [7] is applied to support convergence tunnel until a point very close to (1,1) mutual information point. As shown in Fig. 2, D-ACC is performed after the interleaver \( \Pi_i \). The structure of D-ACC is very simple since it is composed of a memory-1 systematic recursive convolutional codes (SRCC) with octal code generator of \( [3, 2|3]_8 \) followed by heavy puncturing of the coded bits such that coding rate = 1. With a doping rate \( P_A = P_B = P_C = 15 \) for user 1, 2, 3, respectively, the D-ACC replaces every 15-th systematic bits with the accumulated coded bit.

At the receiver D-ACC decoding, denoted as \( D_{dacc} \), is performed using Bahl-Cocke-Jelinek-Raviv (BCJR) algorithm [8] immediately after the equalization. It should be noted here that interleaver between \( D_{dacc} \) and the equalizer is not needed because the extrinsic log-likelihood ratio (LLR) is not exchanged between them.

### B. Destination

The destination consists of a common ISM demapper, and two independent turbo loops because two sources are to be detected. ISM demapper performs demapping of spatial constellation from \( y_i \) with the help of a priori information in the form of LLR provided by the decoder. The demapper output is extrinsic LLR which is then fed into \( D_{dacc} \), deinterleaved, and then decoded by the decoder \( D_1 \).

#### C. ISM Demapper

Let’s consider, for example, user 3. As shown in Fig. 2(b), with the help of a priori information about \( s_1 \) provided by the decoder \( D_1 \) in the form of \( L_{a_1,M} \), the demapper calculates the extrinsic LLR \( L_{e_2,M} \) of the symbol \( s_2 \) from the received signal \( r \) by

\[
L_{e_2,M} = \ln \frac{\Pr(s_2 = +1 | r)}{\Pr(s_2 = -1 | r)} \sum_{s \in S_{+1}} \exp \left\{ -\frac{r - h_1 s_1 - h_2 s_2}{\sigma_n^2} + b_1 L_{a_1,M} \right\} - \sum_{s \in S_{-1}} \exp \left\{ -\frac{r - h_1 s_1 - h_2 s_2}{\sigma_n^2} + b_1 L_{a_1,M} \right\},
\]

(7)

![Diagram](image-url)
where $\mathcal{S}_{s1}, \mathcal{S}_{s2}$ are the sets of superposition symbols having symbol $s1$ being +1 and −1, respectively, with $s1 = 1 - 2b1$. Similarly, with the help of a priori information about symbol $s2$ provided by decoder $D_2$ in the form of $L_{o2, M}$, the extrinsic LLR $L_{e1, M}$ of symbol $s1$ is given by

$$L_{e1, M} = \ln \frac{Pr(s1 = +1|r)}{Pr(s1 = -1|r)} = \ln \frac{\sum_{s1 \in \mathcal{S}_{s1}} \exp \left\{-\frac{|r - h1s1 - h2s2|^2}{\sigma_n^2} + b2L_{o2, M}\right\}}{\sum_{s1 \in \mathcal{S}_{s2}} \exp \left\{-\frac{|r - h1s1 - h2s2|^2}{\sigma_n^2} + b2L_{o2, M}\right\}},$$

(8)

with $s2 = 1 - 2b2$.

The extrinsic LLRs, $L_{e1, M}$ and $L_{e2, M}$, are then used in doped deaccumulator $D_{dacc}$, deinterleaved by $\Pi_1^{-1}$ and $\Pi_2^{-1}$, respectively, to provide a priori LLR $L_{a1, D1}$ and $L_{a2, D2}$, of the coded bits for the decoders $D_1$ and $D_2$. This algorithm also applies for users 1 and 2.

IV. PERFORMANCE EVALUATION AND ANALYSIS

A. EXIT Analysis

This section describes EXIT analysis [9] to observe the convergence properties of the proposed iterative spatial demapper and its corresponding decoders with VI loops for some correlation $p$ values. Fig. 3 shows at destination 3 the source $b1$ EXIT chart of the ISM demapper and the decoder (by VI loop) for $P = 2.5$ dB and $b1 = b2 = b3 = 1$.

The X-axis is mutual information (MI) for a priori LLR $I_{a1, M} = I(x_i'; L_{a1, M})$ and extrinsic LLR $I_{e1, D1} = I(x_i'; L_{e1, D1})$, where $x_i$ and $x_i'$ are shown in Fig. 2 and $L_{a1, M} = \Pi_1^{-1}(L_{e1, D1})$ with $\Pi_1(\cdot)$ being the $\Pi_1$ interleaver function. Here,

$$L_{a1, M}(k) \equiv \begin{cases} L_{e1, M}(k), & k \neq npc, n = 1, \ldots, K, \\ 0, & \text{otherwise}, \end{cases}$$

(9)

where $L_{a1, M}(k)$ is the a priori LLR for $D_{dacc}$ and $k$ being the bit-index.

The decay of ISM demapper EXIT curve depends on each user’s power $P$, the doping rate $P_A$, $P_D$, $P_C$, and the power at the relay $P_r$. For $P = 2.5$ dB and $P_A = P_D = P_C = 15$, Fig. 3 shows that higher power at the relay improves the performance as shown in the figure by lifting up the ISM demapper EXIT curve; among $P_r = \{1, 2, 3\}$ the ISM demapper EXIT curve is located at the highest place with $P_r = 3$ in the EXIT chart that makes the convergence tunnel open until a point very close to (1,1) mutual information point.

B. BER Performance

Bit-error-rate performance is evaluated in two conditions: (a) AWGN channel with random phase difference $\theta$ (equivalent to Rayleigh fading channel with instantaneous power control) and (b) 1-path block Rayleigh fading channel. The BER results in AWGN channel are plotted in Fig. 4(a). It is confirmed from the figure that $P_r = 3$ provides a better BER performance.

The results in 1-path Rayleigh fading channel shows that the average BER is slightly shifted from the theoretical QPSK BER curve. The reason is in three-way relay, the phase difference $\theta$ can not be controlled to be always orthogonal as in QPSK, when $\theta = 0$ and channel amplitude is the same, it results in received constellation $\{-2, 0, 2\}$.

V. Conclusions

A simple iterative spatial demapping (ISM) technique is proposed for simultaneous full data exchange in three-way relaying systems. Based on the a priori log-likelihood ratio (LLR) provided by the decoder, the ISM demapper can distinguish the simultaneously transmitted information, which allows the three users to exchange information simultaneously within only two transmission phases. Our BER performance results as well as EXIT chart analysis show that the performance in AWGN channel (or Rayleigh fading with instantaneous power control) has clear turbo cliff when each user’s transmit power $P = 2.38$ dB with noise variance $\sigma_n^2 = \sigma_i^2 = 1, i \in \{1, 2, 3\}$. The results of average BER performance in block Rayleigh fading channel show that the performance of simultaneous full data exchange in three-way relaying systems is slightly shifted from the theoretical performance of QPSK because of the phase ambiguity.

REFERENCES


BER for each user AWGN channel with random $\theta$

(b) Average BER/PER for each user in 1-path (block) Rayleigh fading channel

Fig. 4. BER performances


