Distributed Turbo Code Forwarding Systematic Bits for Relay Networks

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***Abstract*—In this paper, a practical distributed turbo code (DTC) and its corresponding decoding scheme at destination are presented. The transmission is divided into two phases. In the first phase, the source broadcasts a turbo code to both relay and destination. In the second phase, the relay forwards the decoded systematic bits to the destination in case of no CRC errors. Further, a modified turbo decoder is designed at destination to ensure that the destination makes full use of the received bits whether from source or relay. Simulation results demonstrate a marked BER performance without an increase of computation complexity.**

Keywords- relay network; Distributed codes; turbo coding

I. INTRODUCTION

The main advantage of relay networks was traditionally considered as reducing signal transmit power [1]. Recently, the concept of relay is applied to wireless cooperative system to achieve cooperative diversity gain [2]-[4]. Besides, additional coding gain can be obtained when relay employs the well known decode-and-forward (DF) strategy [5]. Aimed at attaining the maximum benefits promised by cooperative relay network including diversity and coding gain, some distributed coding schemes [6] have been proposed. A distributed turbo coded (DTC) system, which is developed for a two-hop relay network, performs close to the theoretic outage probability bound [7][8] and draws considerable attentions. However, most of the existing DTC schemes assume error free decoding at relay thus ignore the error propagation, which severely undermines the system performance. While [9] devises a DTC scheme to handle error propagation with good performance in theory, it is impractical to use the scheme due to its algorithm's complexity and its assumption that all nodes in the relay network shall know every channel's condition. A more realistic punctured DTC is proposed in [10] using turbo code at source and forwarding parity bits at relay. But its higher successful decoding rate at relay than the conventional DTC is counteracted by discarding part of the received symbols at destination, hence its performance is limited.

In this article, a novel distributed turbo coding scheme is proposed, where the relay forwards systematic bits instead of parity bits as in [10]. Further, a modified turbo decoder is devised at destination for the proposed DTC. Simulation results show that the proposed DTC improves the BER performance with no complexity increase compared with [10].

The paper is organized as follows. In section 2, the proposed DTC scheme is given. The corresponding decoding method is presented in section 3. The simulation results are illustrated in section 4. Finally, section 5 concludes the paper.

II. THE PROPOSED DTC SCHEME

A two-hop relay network is shown in *Fig.* 1 where three nodes are labeled as source (S), relay (R) and destination (D) respectively. The relay is assumed half-duplex and employs DF protocol. Information generated at source can travel to the destination by S-D direct link and the relay aided link. The transmission is divided into two phases. The source broadcasts its information to both relay and destination in the first phase, and the relay forwards the message to the destination in the second phase. The destination recoveries the information generated at source according to the messages received at both phases.

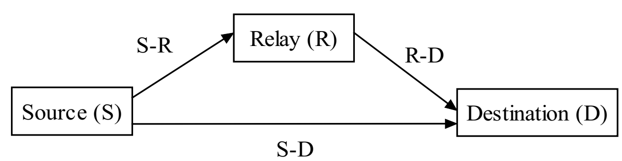

Figure 1. Two-hop relay network

At the beginning of transmission, the binary information sequence $\mathbf{d} = \{d_k; 1 \le k \le N\}$ is encoded by a PCCC encoder, and the parities $\{\mathbf{p}_1; \mathbf{p}_2\}$ are punctured by pattern [0 1; 1 0]. Then the codes are mapped into symbols $\mathbf{x} = \{\mathbf{x}_k; 1 \le k \le N\}$ through BPSK, where $\mathbf{x}_k = (x_k^d, x_k^p)$, x_k^d and x_k^p are systematic symbol and parity symbol respectively. Afterwards, the source broadcasts the symbols $\mathbf{x}$ to both relay and destination.

When relay received the symbols from source, the symbols will be decoded to $\hat{\mathbf{d}} = \{\hat{d}_k; 1 \le k \le N\}$. $\hat{\mathbf{d}}$ is the estimation of $\mathbf{d}$. Whether the decoding is successful will be identified by cyclic redundancy check (CRC) code. If $\hat{\mathbf{d}}$ pass

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the CRC, the relay will sent $\hat{\mathbf{d}}$ to the destination. Otherwise, $\hat{\mathbf{d}}$ will be discarded in order to avoid error propagation and no message would be sent to the destination by the relay.

The received symbols from S-R link, S-D link and R-D link are denoted by $\mathbf{y}_{\rm sr}$, $\mathbf{y}_{\rm sd}$ and $\mathbf{y}_{\rm rd}$ respectively. The destination utilizes the symbols $\mathbf{y}_{\rm sd}$ and $\mathbf{y}_{\rm rd}$ for decoding in case of successful CRC at relay, and uses the symbols $\mathbf{y}_{\rm sd}$ alone for decoding in case of unsuccessful CRC at relay. The detail of the decoding scheme at destination will be shown in next section.

Besides, the received symbols $\mathbf{y}_{\rm sr}=\{\mathbf{y}_{{\rm sr},k};1\le k\le N\}$, $\mathbf{y}_{\rm sd}=\{\mathbf{y}_{{\rm sd},k};1\le k\le N\}$ and $\mathbf{y}_{\rm rd}=\{y_{{\rm rd},k};1\le k\le N\}$ can be expressed by

$$\mathbf{y}_{sr,k}=\sqrt{G_s}h_{sr}\mathbf{x}_k+\mathbf{n}_{sr,k} \tag{1}$$

$$\mathbf{y}_{sd,k}=\sqrt{G_s}h_{sd}\mathbf{x}_k+\mathbf{n}_{sd,k} \tag{2}$$

$$y_{rd,k}=\sqrt{G_r}h_{rd}x'_k+n_{rd,k} \tag{3}$$

Where $\mathbf{y}_{{\rm sr},k}=(y^{\rm d}_{{\rm sr},k},y^{\rm p}_{{\rm sr},k})$ and $\mathbf{y}_{{\rm sd},k}=(y^{\rm d}_{{\rm sd},k},y^{\rm p}_{{\rm sd},k})$,the superscript "d" and "p" mean systematic and parity symbols respectively. x'_k is the corresponding modulation symbol of $\hat{d}_k$. G_s and G_r are transmit symbol power at source and relay respectively. h_{sr} , h_{sd} and h_{rd} represent fading coefficients of S-R, S-D and R-D channel respectively. Noises $\mathbf{n}_{{\rm sr},k}$, $\mathbf{n}_{{\rm sd},k}$ and $n_{{\rm rd},k}$ are zero mean complex Gaussian random variables with two-sided power spectral density of $N_0/2$ per dimension.

III. PROPOSED TURBO DECODER STRUCTURE

The decoding scheme at destination lies on whether or not there is CRC error at relay. *Fig.*.2 describes the decoder scheme.

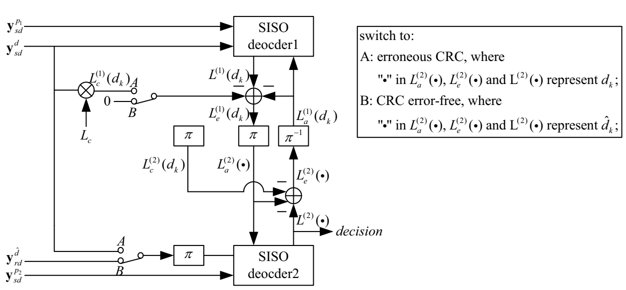

Figure 2. Decoder scheme at destination

A. Relay with Successful CRC

In case of successful CRC at relay, the decoder is a classical turbo decoder and the decoding is based on $\mathbf{y}_{sd}$ from S-D link. As shown in *Fig.*2, the switch turns to A in this case. The parity symbols $\mathbf{y}^p_{sd}$ is de-punctured into $\mathbf{y}^{p_1}_{sd}$ and $\mathbf{y}^{p_2}_{sd}$, and a value of zero for punctured bits is included. The inputs of SISO decoder 1 consist of $\mathbf{y}^d_{sd}$, $\mathbf{y}^{p_1}_{sd}$ and a prior information $L^{(1)}_a(d_k)$ from SISO decoder 2. Likewise, SISO decoder 2 uses $\mathbf{y}^d_{sd}$, $\mathbf{y}^{p_2}_{sd}$ and a prior information $L^{(2)}_a(d_k)$ from SISO decoder 1 for decoding. The extrinsic information $L^{(1)}_e(d_k)$ and $L^{(2)}_e(d_k)$ are calculated by

$$L^{(i)}_e(d_k)=L^{(i)}(d_k)-L^{(i)}_a(d_k)-L^{(i)}_c(d_k)\quad i=1,2 \tag{4}$$

Where $L^{(1)}(d_k)$ and $L^{(2)}(d_k)$ are the a posteriori log-likelihood ratio; $L^{(1)}_c(d_k)$ and $L^{(2)}_c(d_k)$ are S-D channel information which are determined by $\mathbf{y}^d_{sd}$ and channel reliability value L_c .

B. Relay with unsuccessful CRC

In case of unsuccessful CRC at relay, a modified turbo decoder is devised and the decoding is based on $\mathbf{y}_{sd}$ from S-D link and $\mathbf{y}_{rd}$ from R-D link. $\mathbf{y}_{sd}$ consists of the systematic symbols $\mathbf{y}^d_{sd}$ and the parity symbols $\mathbf{y}^p_{sd}$, while $\mathbf{y}_{rd}$ only includes the systematic symbols $\mathbf{y}^{\hat{d}}_{rd}$. As shown in *Fig.*2, the switch turns to B in this case. The SISO decoder 1 uses $\mathbf{y}^d_{sd}$, $\mathbf{y}^{p_1}_{sd}$ and a prior information $L^{(1)}_a(d_k)$ from SISO decoder 2 for decoding. While SISO decoder 2 uses $\mathbf{y}^{\hat{d}}_{rd}$, $\mathbf{y}^{p_2}_{sd}$ and a prior information $L^{(2)}_a(\hat{d}_k)$ from SISO decoder 1 for decoding. The extrinsic information $L^{(1)}_e(d_k)$ and $L^{(2)}_e(\hat{d}_k)$ are calculated by

$$L^{(1)}_e(d_k)=L^{(1)}(d_k)-L^{(1)}_a(d_k) \tag{5}$$

$$L^{(2)}_e(\hat{d}_k)=L^{(2)}(\hat{d}_k)-L^{(2)}_a(\hat{d}_k) \tag{6}$$

Where $L^{(1)}(d_k)$ and $L^{(2)}(\hat{d}_k)$ are the a posteriori log-likelihood ratio. It should be noted here that channel information $L^{(1)}_c(d_k)$ and $L^{(2)}_c(\hat{d}_k)$ is not subtracted from $L^{(1)}(d_k)$ and $L^{(2)}(\hat{d}_k)$ in (5) and (6). This is because the channel information for each SISO decoder is not redundant information to the other SISO decoder.

IV. SIMULATION RESULTS

In this section, the bit error rate (BER) performance of the proposed DTC scheme is provided by computer simulations. At source, we use four-state (memory 2) recursive convolutional code with generator polynomial $([7 \quad 5]7)_8$ for PCCC encoder. And a semi-random interleaver with S=8 is utilized. Both decoders at relay and destination perform at most 5 iterations. The S-R link, R-D link and S-D link are assumed frequency-flat block Rayleigh fading channel where fading coefficients h_{sr}, h_{rd}, h_{sd} are constant within one frame and change independently from one frame to another.

Four relay scenarios are considered. The distances of S-R, R-D and S-D link are denoted by L_{sr}, L_{rd} and L_{sd} respectively. Given $L_{sd} = a$, the four scenarios are as follows：

a) *Scenario (A):* $L_{sr} = a/4$, $L_{rd} = 3a/4$;

b) *Scenario (B):* $L_{sr} = a$, $L_{rd} = a$;

c) *Scenario (C):* $L_{sr} = a/2$, $L_{rd} = a$;

d) *Scenario (D):* $L_{sr} = a/4$, $L_{rd} = a$.

Figures 3-6 show the BER performance of the proposed DTC, the conventional DTC[7] and the punctured DTC[10]. To make the comparison fair, the relay of conventional DTC in our simulation is assumed not to forward message when decoded bits at relay trigger CRC failure. At BER=10^{-4} , it can be seen from *Figs.* 3-6 that the proposed DTC achieves around 1.2 dB, 1.3dB, 1.5dB and 1.4dB SNR gain over the conventional DTC, and outperforms the punctured DTC around 1.8dB, 1.3dB, 1.8dB and 2.0dB SNR gain respectively.

The main advantage of punctured DTC and proposed DTC over conventional DTC is the turbo encoding scheme at source. The scheme increases the successful decoding rate at relay, which can alleviates the error propagation. This explains why the punctured DTC and proposed DTC outperforms the conventional DTC as shown in *Figs.*3-6.

At destination, the punctured DTC discards half of parity bits from S-D link if the parity bits from R-D link is available. This indiscriminate method suffers from information loss. The proposed DTC overcomes the shortcoming by making full use of all the received bits whether from S-D link or R-D link. And the performance of proposed DTC over punctured DTC gets better when the S-R link improves, as shown in *Figs.* 4-6.

From the perspective of computing complexity, the proposed DTC and punctured DTC have the same computing complexity at source for they share the same encoding scheme. Upon the successful decoding at relay, the punctured DTC carries out a re-encoding procedure by a single RSC encoder and the proposed DTC avoids re-encoding, so the later has less computing burden than the former. Further, the modified turbo decoder of the proposed DTC at destination has the same structure as standard turbo decoder, so it doesn't need extra computation. In a word, the proposed DTC outperforms the punctured DTC without an increase of computing complexity.

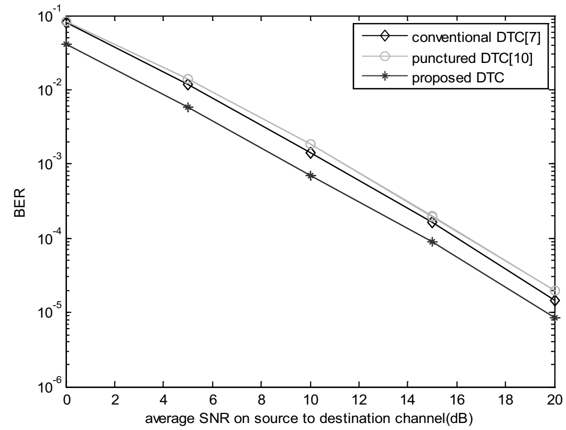

Figure 3. BER performance comparison of DTCs in scenario (A)

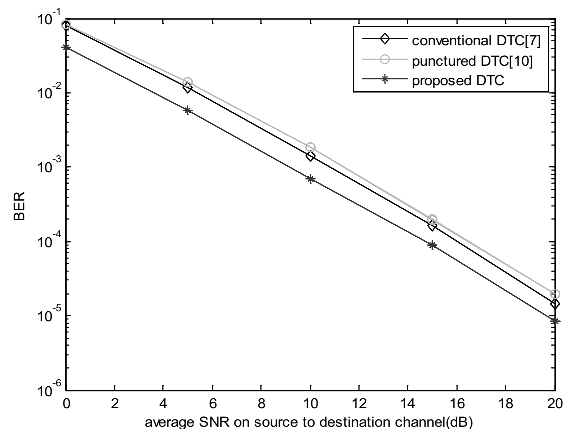

Figure 4. BER performance comparison of DTCs in scenario (B)

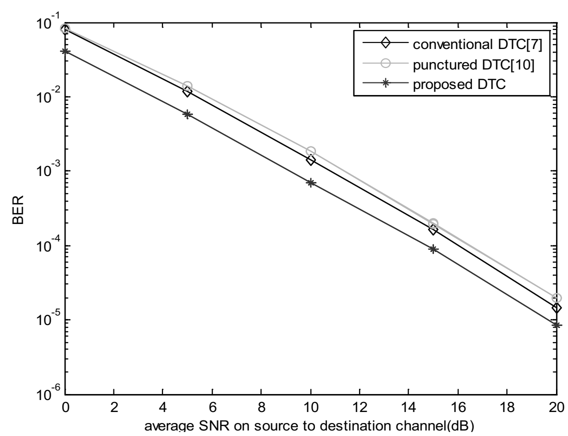

Figure 5. BER performance comparison of DTCs in scenario (C)z

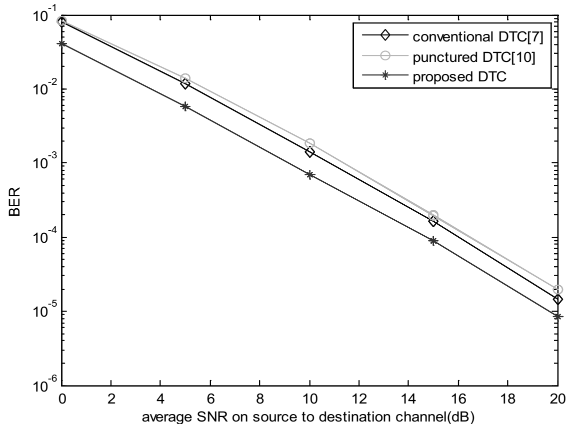

Figure 6. BER performance comparison of DTCs in scenario (D)

V. CONCLUSIONS

A practical DTC scheme is proposed in relay networks, where the transmission includes two phases. In the first phase, the code broadcasted by source to both relay and destination is turbo code, and the message to be forwarded by relay in the second phase is chosen to be "systematic bits". Accordingly, a modified decoder is devised at destination in order to effectively combine all the received messages from both source and relay. While remaining the same complexity as punctured DTC, the proposed DTC achieves better BER performance compared with the conventional DTC and the punctured DTC.

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