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A New Stopping Criterion for BICM-ID System Based on Cross-Entropy

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Abstract

This paper proposes a new stopping criterion for BICM-ID (bit-interleaved coded modulation with iterative decoding) system based on the CE (cross-entropy) stopping criterion. Unlike the conventional CE stopping criterion, the new scheme only computes and compares the cross-entropy value of the odd bits of the entire frame bits. We name the proposed new criterion as Partial-CE stopping criterion. The new criterion can reduce about 50% computation complexity of the BICM-ID receiver. Simulations comparing the new criterion with the original CE stopping criterion show that the proposed Partial-CE scheme can achieve similar performances in terms of BER and the average iteration numbers.

*Keywords:*BICM-ID, SISO decoder, extrinsic information, a prior information, cross-entropy

1. Introduction

Bit-interleaved coded modulation with iterative decoding (BICM-ID) is a promising scheme for its excellent performances both in AWGN and in Rayleigh fading channels [1]. The iterative decoding algorithm at the receiver especially makes the BICM-ID a very smart technique for the capability of achieving large coding gains without bandwidth expansion [2, 3]. The iterative decoding process is between the soft-input soft-output (SISO) decoder and the demapper, which is different from the turbo iteration of the receiver. In turbo receiver, the iterative process is between the two inner SISO decoders [4]. The similarity between the two iterative decoding algorithms is that they are both designed to achieve the global optimum through a step-by-step local search. In the iteration cycle, the BER (bit-error-rate) decreases as the iteration number increases, but the incremental improvement gradually diminishes. The conventional iterative decoding algorithm is a fixed scheme that with fixed iteration numbers M. Usually M is set with the worst corrupted frames in mind. However, most frames need fewer iterations to converge. After a certain number of iterations, the system gets

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very little performance improvement with any further iteration. Thus, to reduce the long decoding time delay and to decrease the decoding power consumption, the stopping criterions, which can timely stop the unnecessary iterations, are put forward [5-9], such as the cross-entropy (CE) stopping criterion [5], the sign-change-ratio (SCR) stopping criterion [6], the hard-decision-aided (HDA) stopping criterion [6], the measurement of reliability (MOR) stopping criterion [7], the convolution-sum (CS) stopping criterion [8], the Min-CorrEx stopping criterion [9] etc. Although the stopping criterions mentioned above are initially proposed for turbo receiver, if properly modified, they can also be used in BICM-ID receiver to reduce the unnecessary iterations. S. Zhang has successfully modified the CE stopping criterion that originally devised for turbo receiver to be applied to the BICM-ID receiver [10]. The iteration number is greatly reduced as expected, but the computation of cross-entropy value of every decoding bit increases the complexity of the BICM-ID receiver. This paper proposes a new stopping criterion named Partial-CE stopping criterion. As the name reveals, the proposed criterion only needs to compute and compare the odd bits of the entire decoding bits, which can substantially reduce the computation complexity of the BICM-ID receiver and decrease the power consumption at the same time.

The paper is organized as follows: Section II introduces the structure of BICM-ID receiver. Section III gives a general review about the CE stopping criterion and section Ⅳintroduces our proposed new stopping criterion. Simulation results are shown in section Ⅴ, and section Ⅵ concludes the paper.

2. The Structure of BICM-ID Receiver

Fig.1 shows the structure of BICM-ID receiver. Different from the turbo receiver, which conducts the iteration between the two inner SISO decoders, the BICM-ID decoding iteration is between the demapper and the SISO decoder.

Before being applied to the SISO decoder, the extrinsic information $L_e(c_t(i))$ of the demapper is deinterleaved. The deinterleaved output is considered as the a priori information $L_a(c_t(i))$ of the SISO decoder, where

$$L_a(c_t(i)) = \log\left[\frac{P(c_t(i)=0)}{P(c_t(i)=1)}\right] \tag{1}$$

$$L_e(c_t(i)) = \log\left[\frac{P(c_t(i)=0\,|\,r_t, L_a(c_t))}{P(c_t(i)=1\,|\,r_t, L_a(c_t))}\right] - L_a(c_t(i)) \tag{2}$$

Similarly, the extrinsic information of the SISO decoder is then interleaved and fed back to the demapper as the a prior information of the next iteration.

We note that $L_a(c_t(i))$ is set to be zero during the first iteration cycle. At the last iteration, the hard decisions that getting from the SISO decoder, is obtained based on the extrinsic bit information. The iterative process won't stop until the preset maximum iteration number M is reached.

3. The CE Stopping Criterion

CE (cross-entropy) is a measurement of how close two distributions are. For the distributions p and q of a finite alphabet χ, CE is defined as

$$H[p,q] = \sum_{x\in\chi} p(x)\log\frac{p(x)}{q(x)} \tag{3}$$

In BICM-ID system, assume that $L^{i}_{\mathrm{DEC}}(\hat{c}_k)$ represents the LLR (log-likelihood-ratio) of the decoded bit c_k ($k=1, 2, 3,\ldots,N$) after the i_{th} iteration and $L^{i-1}_{\mathrm{DEC}}(\hat{c}_k)$ represents the LLR of the $(i-1)_{th}$ iteration respectively. Thus, the CE value between the decoding outputs of the two consecutive iterations is

$$H[P^{i}_{DEC}(\hat{c}^{i}_{k}),P^{i-1}_{DEC}(\hat{c}^{i-1}_{k})]$$

$$=\sum_{\hat{c}^{i}_{k}}P^{i}_{DEC}(\hat{c}^{i}_{k})\log\frac{P^{i}_{DEC}(\hat{c}^{i}_{k})}{P^{i-1}_{DEC}(\hat{c}^{i-1}_{k})}$$

$$=P^{i}_{DEC}(\hat{c}^{i}_{k}=0)\log\frac{P^{i}_{DEC}(\hat{c}^{i}_{k}=0)}{P^{i-1}_{DEC}(\hat{c}^{i-1}_{k}=0)}$$

$$+P^{i}_{DEC}(\hat{c}^{i}_{k}=1)\log\frac{P^{i}_{DEC}(\hat{c}^{i}_{k}=1)}{P^{i-1}_{DEC}(\hat{c}^{i-1}_{k}=1)} \tag{4}$$

where

$$P_{DEC}(\hat{c}_k=0)=\frac{e^{L_{DEC}(\hat{c}_k)}}{1+e^{L_{DEC}(\hat{c}_k)}} \tag{5}$$

$$P_{DEC}(\hat{c}_k=1)=\frac{1}{1+e^{L_{DEC}(\hat{c}_k)}} \tag{6}$$

Substituting (5) and (6) into (4), we get CE:

$$H[P^{i}_{DEC}(\hat{c}^{i}),P^{i-1}_{DEC}(\hat{c}^{i-1})]$$

$$=\sum_{k=1}^{N}\left[\frac{L^{i-1}_{DEC}(\hat{c}^{i-1}_{k})-L^{i}_{DEC}(\hat{c}^{i}_{k})}{1+e^{L^{i}_{DEC}(\hat{c}^{i}_{k})}}+\log\frac{1+e^{-L^{i-1}_{DEC}(\hat{c}^{i-1}_{k})}}{1+e^{-L^{i}_{DEC}(\hat{c}^{i}_{k})}}\right] \tag{7}$$

As the iteration continues, the decoding outputs between the two consecutive iterations i and $i-1$ come to be approximately the same. Therefore, the CE value becomes smaller and smaller. When the iteration proceeds to a certain extent, although the iteration number continues increasing, the CE value won't decrease any more. This means that the iteration has achieved the decoding limit. Then, the iterative decoding process can be terminated. We usually set a threshold to effectively stop the unnecessary iterations:

$$T(i)=\sum_{k=1}^{N}\left[\frac{L^{i-1}_{DEC}(\hat{c}_k^{\,i-1})-L^{i}_{DEC}(\hat{c}_k^{\,i})}{1+e^{L^{i}_{DEC}(\hat{c}_k^{\,i})}}+\log\frac{1+e^{-L^{i-1}_{DEC}(\hat{c}_k^{\,i-1})}}{1+e^{-L^{i}_{DEC}(\hat{c}_k^{\,i})}}\right] \tag{8}$$

$$<Threshold$$

4. The Proposed Stopping Criterion

As Fig.2 and Fig.3 have shown, comparing with the conventional BICM-ID system that with fixed iteration numbers, although the system that using CE stopping criterion gets little performance degradation in terms of BER, it can greatly reduce the iteration numbers. The iteration number can be reduced from 10 to 4 at low SNR (signal-to-noise ratio) sections and 3 at high SNR sections respectively. However, the computation of CE value of every decoding bit brings extra complexity of the BICM-ID receiver as BICM-ID system often sets a large frame size to achieve good performances. Thus, the superiority of CE stopping criterion, which can timely stop the iteration process, greatly reduce the decoding latency, vastly decrease the receiver power consumption, is lessened.

Thus, we devise the new efficient Partial-CE stopping criterion. The new stopping criterion only chooses odd bits of the entire frame bits as the sample bits to conduct the CE value computation and comparison, which can decrease 50% CE calculation of the receiver and reduce the power consumption of the BICM-ID receiver at the same time.

$$T(i)=\sum_{k=1,k+2}^{N}\left[\frac{L_{DEC}^{i-1}(\hat{c}_k^{i-1})-L_{DEC}^{i}(\hat{c}_k^{i})}{1+e^{L_{DEC}^{i}(\hat{c}_k^{i})}}+\log\frac{1+e^{-L_{DEC}^{i-1}(\hat{c}_k^{i-1})}}{1+e^{-L_{DEC}^{i}(\hat{c}_k^{i})}}\right] \tag{9}$$

Just as the conventional CE stopping criterion, the new Partial-CE stopping criterion also set a threshold to effectively stop the iteration process

$$T(i)=\sum_{k=1,k+2}^{N}\left[\frac{L_{DEC}^{i-1}(\hat{c}_k^{i-1})-L_{DEC}^{i}(\hat{c}_k^{i})}{1+e^{L_{DEC}^{i}(\hat{c}_k^{i})}}+\log\frac{1+e^{-L_{DEC}^{i-1}(\hat{c}_k^{i-1})}}{1+e^{-L_{DEC}^{i}(\hat{c}_k^{i})}}\right] < Threshold \tag{10}$$

CE stopping criterion often sets the threshold as $10^{-4}T(1)$, likewise, we also set the threshold of the new Partial-CE stopping criterion as $10^{-4}T(1)$.

5. Simulation Results

We first introduce the simulation environments: BICM-ID system; rate 1/2 convolutional code; 8PSK modulation; SP mapping; Rayleigh fading channel; frame size 2048; for stopping criterions, maximum iteration number $M=10$; for both CE stopping criterion and the new proposed Partial-CE stopping criterion, when $T(i)<10^{-4}T(1)$, stop iteration. Note that a fixed scheme, which uses 10 as the fixed iteration number is included for comparison.

Fig.4 shows that the new proposed Partial-CE stopping criterion can get similar performances in terms of BER with the conventional CE stopping criterion and there is almost no performance degradation compared with the fixed scheme.

Fig.5 shows that the new Partial-CE stopping criterion can reduce large amounts of iteration numbers just as the conventional CE criterion does compared with the fixed scheme. The iteration numbers can be reduced from 10 to 4 at low SNR sections and 3 at relatively high SNR sections respectively. Compared with the conventional CE stopping criterion, the Partial-CE stopping criterion has additional advantages. It can reduce 50% complexity of CE calculation of the receiver as it only considers the odd bits of the entire decoding bits. Meanwhile, it also decreases the power consumption of the BICM-ID receiver.

6. Conclusions

This paper proposes a new simple stopping criterion named Partial-CE stopping criterion for BICM-ID system based on the conventional CE stopping criterion. Unlike the CE criterion, the devised Partial-CE stopping criterion only computes and compares the odd bits of the entire decoding bits, which provides the superiority of reducing 50% complexity of CE calculation of the BICM-ID receiver. Although with less computation, it can achieve similar performances with the conventional CE stopping criterion in terms of BER and the average iteration numbers. Above all, the excellent performances and the simplicity jointly make the new proposed Partial-CE stopping criterion more optional in BICM-ID system.

7. Acknowledgment

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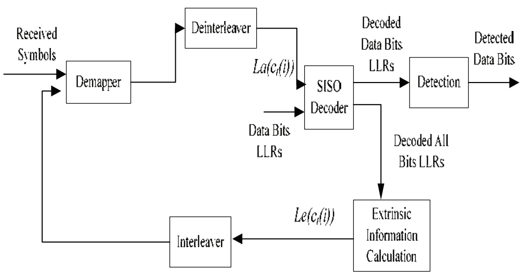

Figure 1. The structure of BICM-ID receiver

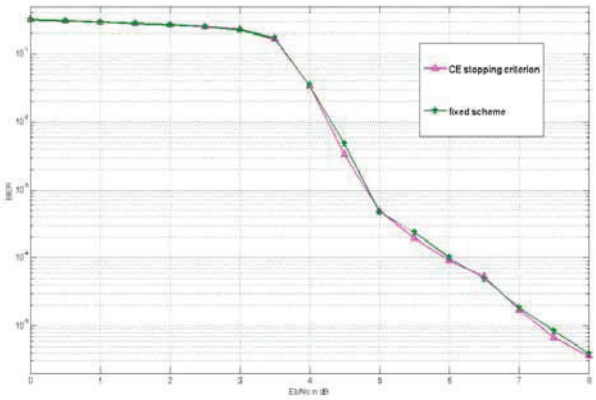

Figure 2. BER performance comparison of CE stopping criterion and the fixed scheme

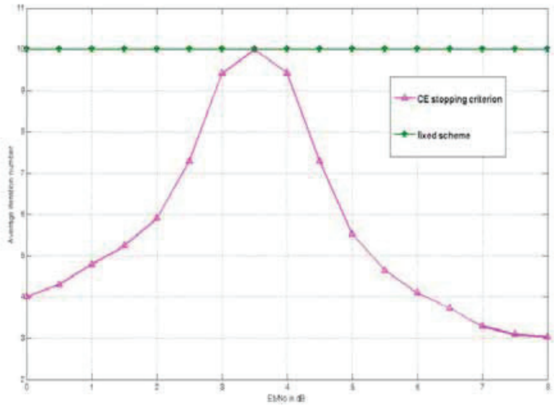

Figure 3. Comparison of average iteration numbers of CE stopping criterion and the fixed scheme

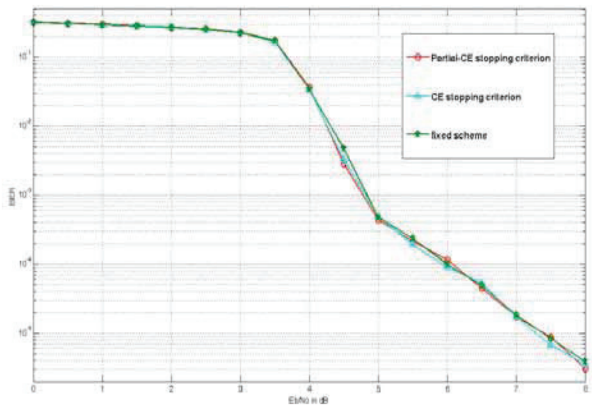

Figure 4. BER performance comparison of Partial-CE stopping criterion, CE stopping criterion and the fixed scheme

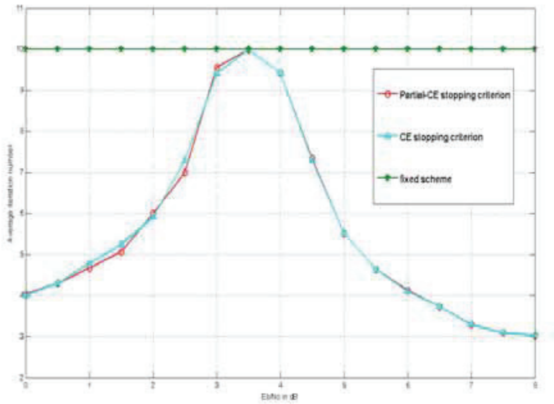

Figure 5. Comparison of average iteration numbers of Partial-CE stopping criterion, CE stopping criterion and the fixed scheme