A Self-Adaptive Decoding Scheme for BICM-ID Embedded Turbo Codes

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Abstract

This paper proposes a self-adaptive decoding scheme based on cross-entropy (CE). Good BER performance can be achieved with lower complexity. The fixed minimum iterative number scheme has been proposed to modify the shortage of the traditional stopping criterion scheme, whose calculations of CE expend hardware resource too much. However, iterative numbers which correspond to different SNRs are varied. It is improper to set a unique minimum iterative number (Imin) for all SNRs. In order to further improve the performances, this self-adaptive decoding scheme is proposed. For various SNRs, different minimum iterative numbers, which are determined by the statistics of the iterative numbers, should be set instead of being unique. The SNR criterion is also adopted in this scheme to further reduce the complexity. Simulation results confirm that the iterative receiver with this self-adaptive scheme has achieved a similar performance with the fixed iterative number scheme but it is of a considerably reduced complexity due to the decreased iterative number of decoding and fewer calculations of CE.

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1. Introduction

In recent years, turbo codes have become a major focus of coding research and applications. They have been shown to perform extremely well with computationally efficient iterative decoding [1, 2]. Bit-interleaved coded modulation (BICM) was first introduced by Zehavi [3], and further studied by Caire [4] to improve system performance over Rayleigh fading channels. Iterative joint decoding and demodulation assisted BICM referred to as BICM-ID has been proposed [5]. It has been proved as an effective transmission scheme without bandwidth expansion.

The iterations in the receiver are required to be seriously scheduled to achieve a good performance and complexity trade-off. The traditional stopping criterion has been adopted to reduce the total iterative number of the receiver. Many systems embedded stopping criterion have been utilized to achieve good performances with fewer computations [6, 7, 8]. Nevertheless, the calculations of CE in this traditional
stopping criterion scheme still expend hardware resource too much. In order to ameliorate this shortage, the fixed minimum iterative number scheme has been adopted. However, iterative numbers which correspond to different SNRs are varied. It is improper to set a unique minimum iterative number for all SNRs. In order to further improve the performances, this self-adaptive decoding scheme is proposed. Before the stopping criterion has been adopted, the receiver will activate for minimum iterative number (I_{min}) times. The minimum iterative numbers, which are determined by the statistics of the iterative numbers, are not unique for various SNRs. To further reduce the necessary iterative numbers, the SNR criterion is also adopted. By using this self-adaptive decoding scheme, lower complexity should be achieved due to the decreased the total iterative number of decoding and fewer calculations of CE.

The remainder of this paper is organized as follow:

In Section II, short overview of BICM-ID embedded turbo codes system is given and different schemes for the iterative receiver are shown in Section III. In Section IV, there are the simulations results, followed by the conclusions in Section V.

2.System Model

The system structure of BICM-ID embedded turbo codes is shown in Figure.1. The iterative receiver with a turbo decoder is considered as a two-component concatenated system where the two RSC decoders are viewed as a single entity. Soft information is passed between the demapper and the turbo decoder (receiver iteration).

For each receiver iteration of the turbo decoding, information is also exchanged between two RSC decoders and the demapper does not see this exchanging of information between the two RSC decoders (decoding iteration).

However, in this conventional schedule, the two kinds of iterations bring a high complexity and delay. In general, a simple iteration schedule, which decoding iteration is omitted, is adopted widely for the iterative receiver. For each time of the receiver iteration, the activation number of the three components has been reduced to 3. It is of a considerably reduced complexity due to the significantly decreased iterative number.

3.Different Schemes for Iterative Receiver

3.1. The Fixed Iterative Number Scheme

When the iterative algorithm is adopted, the number of iterations (I_d), which is fixed for the iterative decoder, should be set first. In this fixed iterative number scheme, a proper iterative number can be chosen by using an experimental method. The BER performance curves of BICM-ID embedded turbo codes with different fixed iterative numbers are shown in Figure.2. It is clearly shown that, the larger iterative number would result in the better BER performances; however it also brings in more complexity. Considering the computational complexity, I_d=20 is a better selection for the number of receiver iteration, with a great performance gains approached to I_d>20.

3.2. The Traditional Stopping Criterion Scheme

Cross-entropy is a measure of the difference between two probability distributions. For two distributions p and q of a finite alphabet \( \chi \), the cross-entropy is defined as
\[ H[p, q] = \sum_{x \in X} p(x) \log \frac{p(x)}{q(x)} \]  

(1)

The principle of minimum cross-entropy is a generalization of the statistical inference scheme. It can be used as a stopping criterion for iterative decoding of binary block and convolutional codes [9].

Formally, the principle of cross-entropy minimization is, given an a priori distribution \( q(x) \), determine the “closest” distribution (in the cross-entropy sense) \( p(x) \), which satisfies the given constraints on its moments. That is, find \( p(x) \) such that

\[ H[p, q] = \min_{s} H[s, q] \]  

(2)

subject to

\[ \sum_{x} p(x) = 1 \]  

(3)

and

\[ E_p[f_i(x)] = 0 \quad i = 1, 2, ..., N \]  

(4)

where \( E_p \) is the expectation over the distribution \( p \), and \( f_i \) are functions in \( x \) such that (4) represent the equality constraints on the moments of \( x \).[10]

Stopping criterion based on the cross entropy (CE) of the decoder outputs is considered [9]. If the iterative process converges, we can make some assumptions given by [11]. Then, the CE can be defined as

\[ T(k) = \sum_{t} \left[ \frac{\Lambda^{k-1}(\hat{c}^{k-1}_t) - \Lambda^k (\hat{c}^k_t)}{1 + \exp(\Lambda^k (\hat{c}^k_t))} \right. \\
+ \log \left. \frac{1 + \exp(-\Lambda^{k-1}(\hat{c}^{k-1}_t))}{1 + \exp(-\Lambda^k (\hat{c}^k_t))} \right] \]  

(5)

Simply, the iteration will be stop once the CE is smaller than a threshold. If that threshold is not achieved, the receiver will process the maximum number of receiver iterations (Idmax).

3.3. The Fixed Minimum Iterative Number Scheme

CE has been used as a stopping criterion to reduce the complexity. However, the calculations of CE in this traditional stopping criterion expend hardware resource too much. In order to reduce the complexity, the minimum iterative number scheme has been proposed: a minimum iterative number (Imin) should be set first, after the iterative receiver activates Imin times, the stopping criterion based on CE will be used for the rest numbers of iterations.
Fig.1: The system structure of BICM-ID embedded turbo codes.

Fig.2: BICM-ID embedded turbo codes with different fixed iterative numbers for Rayleigh channels.

The value of Imin can be determined by an experimental method named SNR criterion. When BER=$10^{-5}$, once the SNR difference between the two curves (one is $I_d=20$, the other one is a contrast line) is about 0.1dB, the performance improvements should be considered up to the required. Then Imin can be set the same as the iterative number of this contrast line.

For the first Imin times iterations, the calculation number of CE is only one ($T(1)$ will be used for the rest iterations as the reference), and there is no comparison. The complexity of the computations has been decreased by this scheme.

3.4 A Self-adaptive Decoding Scheme

However, iterative numbers which correspond to different SNRs are varied. It is improper to set a unique minimum iterative number for all SNRs. Average iterative number per frame ($\bar{I}$) is shown in Fig.3. I can be viewed as a necessary iterative number on average. Subsequently, Imin is set as $\bar{I}$ instead of the unique number. (Because the iterative number must be an integer, $\left\lfloor \bar{I} \right\rfloor$ will be used in the actual implementation.)

To further improve the performances, the SNR criterion has also been considered in this proposed scheme. For Rayleigh channels, performance curves with different fixed iteration numbers are shown in Fig.4, and Imin can be set to 7 by the SNR criterion.
For $I_d=7$, due to its good BER performance, it is unnecessary for a region of SNRs to set $I_{\text{min}}$ as $\bar{I}$, which is larger than 7. In this case, $I_{\text{min}}$ should be set as 7 to further reduce the necessary iterative number.

According to the description above, this self-adaptive decoding scheme is proposed: before the stopping criterion has been adopted, the receiver will activate for minimum iterative number ($I_{\text{min}}$) times. $I_{\text{min}}$ can be defined as

$$ I_{\text{min}} = \begin{cases} \left\lfloor \bar{I} \right\rfloor, & \text{if } \bar{I} < 7 \\ 7, & \text{if } \bar{I} \geq 7 \end{cases} $$ (1)

The minimum iterative numbers with different schemes are shown in Fig.5. Compared with the fixed minimum iterative number scheme, fewer necessary iterative numbers can be acquired by this self-adaptive scheme. Because of the application of CE for the rest iterations, the total activation number of the three components will be reduced for each frame. Much lower complexity than the fixed iterative number scheme has been achieved.

![Fig.3: The average iterative number per frame.](image)

![Fig.4: Performance curves with different fixed iterative numbers.](image)
Fig. 5: The minimum iterative numbers with different schemes.

Fig. 6: Performance curves with different schemes for Rayleigh channels.

4. Simulation Results

The performance curves with different schemes are shown in Fig. 6. For all schemes, the frame size is L=1530 and the code rate is Rate=1/2. We only consider QPSK, Gary mapping and Rayleigh fading channels in the transmission environment. Id=ldmax=20 and the threshold set to 0.001T(1). The simple iteration schedule is adopted in the receiver.

In this scheme, the fixed iterative number and the traditional stopping criterion schemes are separately used in different regions of the iteration. After the present iterative number is larger than the Imin, the stopping criterion based on CE will be adopted.
It is clearly shown that: by using this self-adaptive decoding scheme, the similar good BER performances with the fixed iterative number scheme can be achieved and the total activation number of the three components can be reduced. Compared with the fixed minimum iterative number scheme, which has a lower complexity than the fixed iterative number scheme, the complexity performances can be further improved resulting from the fewer necessary iterative numbers.

5. Conclusion

This paper proposes a self-adaptive decoding scheme based on CE for BICM-ID embedded turbo codes. In order to achieve good BER performances with further lower computation complexity, before the traditional stopping criterion based on CE is adopted, the iterative receiver will activate for Imin times. The option of Imin is self-adaptive instead of being unique. Simulation results confirm that the iterative receiver with this proposed scheme has achieved the similar performance with the fixed iterative number scheme but it is of a reduced complexity due to the significantly decreased total iterative number of decoding operations and fewer calculations of CE.

References