植基於模糊機制之渦輪碼解碼停止疊代演算法

A Stop Criterion based on Fuzzy Scheme for Turbo Decoding

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摘要

渦輪碼之解碼演算法，利用反覆疊代修正對解碼位元之可靠度的值，以達到其解碼的效益。研究文獻中，一般反覆疊代 8 次，其解碼位元的信賴度值，即可達到收斂。不過，渦輪碼是一種軟式輸入軟式輸出的解碼架構，其每一次的解碼均需大的運算量，這將會受限它在強調低功率低運算裝置的行動通訊上之發展與應用。在實驗觀測中，當訊雜比高時，其位元可靠度(BER)之解碼並不須 8 次疊代即可收斂，而傳統上，設定固定次數的解碼將會耗費不必要的運算能源。因此，本文提出一個新的停止疊代方法，利用通道訊雜比及解碼時輸出之額外資訊量(EXIT)的模糊機制，可有效的改善解碼時的疊代次數。由實驗得知，利用此一停止疊代的機制平均可節省 1/2 的疊代次數，且其對應的位元錯誤率對訊雜比的效能並無明顯的損失。

關鍵詞：渦輪碼、疊代停止條件、模糊機制、解碼增益

ABSTRACT

As the number of iterations increases, the soft inputs and outputs of a turbo decoder gradually become more reliable. Take the effect into account, several adaptive iterative decoding algorithms for turbo codes were proposed so as to reduce decoding delay. In this paper, we propose a novel method that is an efficient fuzzy adaptive scheme to improve the iteration times of decoding. Experimental results indicate that the proposed fuzzy scheme can reduce down to about 1/2 iteration, while this scheme is no coding gain loss than that of conventional turbo decoders over an AWGN channels.

Keywords: iterative turbo decoding, fuzzy adaptive scheme, stopping criteria, coding gain.

I. INTRODUCTION

In digital wireless communication systems, powerful channel coding is mandatory in order to obtain good transmission performance. C.Berrou [1] first proposed a kind of new class of convolutional codes called Turbo codes, which have near Shannon limit error correcting ability with relatively simple component codes and a large interleaver. A required $\frac{E_b}{N_O}$ value of 0.7 dB was reported for BER of 10^{-5} and code rate of $\frac{1}{2}$.

Turbo codes use iterative decoding and soft input/soft output. The Bahl_Jelinek algorithm, also known as symbol-by-symbol MAP(*maximum a posteriori*) algorithm, is optimal for estimating the output of a Markov process observed in channels . The many types of MAP algorithm are proposed. And the iterative MAP algorithm needs a large number of iterative times. But in practice large decoding delay, brought by a large number of iteration times in the Turbo decoder, is difficult to satisfy the requirement of communication that has strict delay restriction, especially for the real time data transmission. To reduce the iteration times, some algorithms named adaptive iterative algorithms, appeared in [2-6]. They have their own advantages and disadvantages. The algorithm proposed in [2] estimates the second moment of the SNR of the soft output and then evaluate the noise variance σ^2 at every stage. The algorithm terminates the decoding process when the noise variance σ^2 is large enough. Although iteration times are adaptive and the average number of iteration times is reduced, the average iteration times are still very large. Cross entropy algorithm [7], by computing the cross entropy T(i) of the decoder's soft output, stop the iterative decoding. The CRC bits are introduced into the frame to reduce decoding iteration delay [6]. A kind of iterative algorithm reduces the average iteration times by obtaining the variance of the decoder's soft output. BER-estimation criterion stops the iterative decoding process by estimating the block error rate with the soft output of decoder.

This paper is organized as follows. Turbo codes use the recursive systematic convoluational codes (RSC) which will be discussed in section II. In the next part of this paper (section III) we will present the MAP decoding algorithm of Turbo codes. In section IV we will discuss our proposed method. Then the conclusions are finally drawn.

II. TURBO DECODING

The effectiveness of a turbo decoding process [1] is based on iterating the MAP algorithm. The formulation of the MAP algorithm can be briefly described as follows [2]. Given a received codeword sequence $\underline{y}$, the MAP algorithm computes the *a posteriori* Log Likelihood Ratio (LLR) $L(u_k|\underline{y})$ for each decoded bit u_k at time k as

$$L(u_k|\underline{y}) = \ln\left(\frac{\sum_{(s',s),u_k=+1} \alpha_{k-1}(s') \cdot \gamma_k(s',s)\beta_k(s)}{\sum_{(s',s),u_k=-1} \alpha_{k-1}(s') \cdot \gamma_k(s',s)\beta_k(s)} \right) \quad (1)$$

In above equation, the terms $\alpha_{k-1}(s')$, $\beta_k(s)$ and $\gamma_k(s',s)$ represent the forward path metric, the backward path metric and the branch metric, and can be computed respectively as

$$\alpha_k(s) = \sum_{all\ s'} \alpha_{k-1}(s') \cdot \gamma_k(s',s) \quad (2)$$

$$\beta_{k-1}(s') = \sum_{all\ s} \beta_k(s) \cdot \gamma_k(s',s) \quad (3)$$

$$\gamma_k(s',s) = P(u_k) \cdot P(\underline{y}_k|\underline{x}_k), \quad (4)$$

where $P(u_k)$ means the *a priori* probability of the decoded bit u_k and $P(\underline{y}_k|\underline{x}_k)$ denotes the conditional joint probability of the codeword $\underline{y}_k = (y_{k1}, \cdots, y_{kl}, \cdots, y_{kN})$ that given the transmitted codeword $\underline{x}_k = (x_{k1}, \cdots, x_{kl}, \cdots, x_{kN})$ at time k and N is the number of bits in each codeword.

III. FUZZY ADAPTIVE SCHEME

In this section, we describe the proposed fuzzy adaptive stopping scheme.

A. Motivation.

Fig. 1 shows at the same BER performance condition that Eb/No and iteration are dependent, when appears higher SNR, i.e., expression exists higher Eb/No then only needs small number of iterations decoding times.

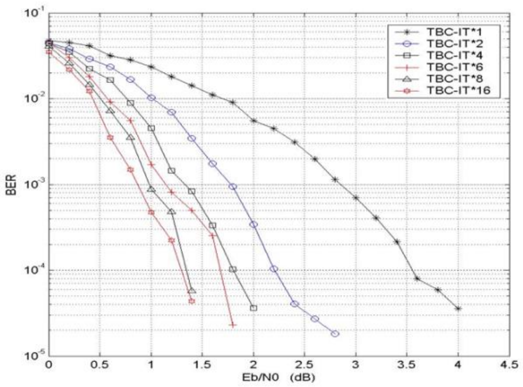

Fig. 1 Eb/No vs. iterations.

Fig. 2 indicates after adding the iteration times that mean of absolute of extrinsic information (EXIT) value is stronger, and if the decoding is convergent, it becomes saturated.

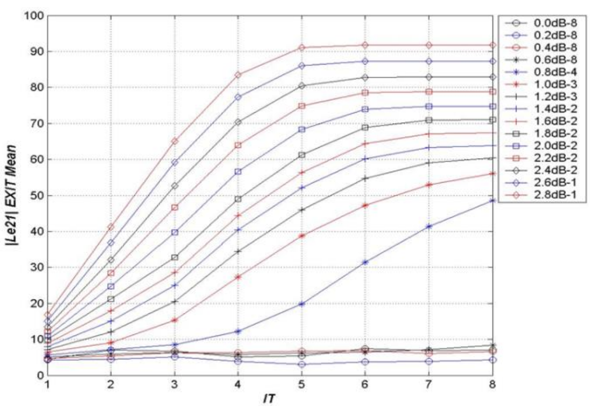

Fig. 2 EXIT vs. iterations.

B. Fuzzy Adaptive Stopping Criterion

The measurements of SNR and the mean of absolute of extrinsic information values decide next iteration whether continue or not. The fuzzy adaptive scheme is structured as following Fig. 3.

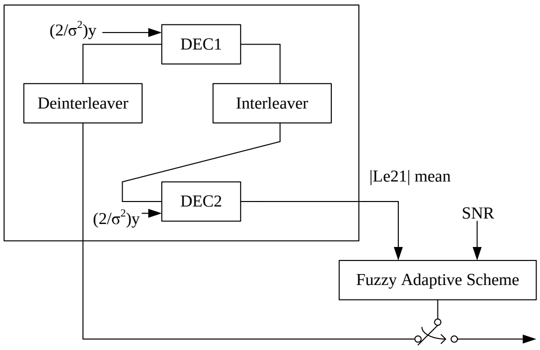

Fig. 3 The fuzzy adaptive structure.

SNR membership function is regarded as an input, and defined its relation variable denoted as X. E.g., let X=SNR, and if X equals to 1.4 dB, then the Degree function is equal to (0.8 0.2), denoted as Dx = (0.8, 0.2), as following Fig. 4 SNR membership function.

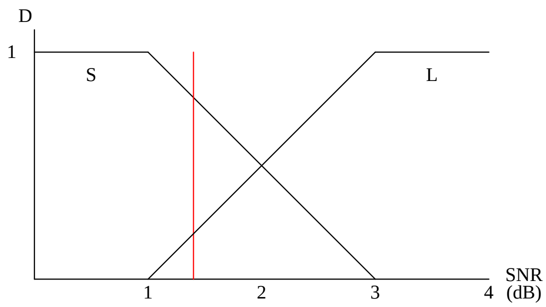

Fig. 4 SNR membership function.

EXIT membership function is a mean of absolute of extrinsic information after one iteration. It is also regarded as an input, and defined its relation variable denoted as Y expressed mean of |Le21|. E.g., let Y=|Le21|, and if Y equals to 20, then the Degree function is equal to (0 1), denoted as Dy = (0, 1), as Fig. 5 EXIT membership function.

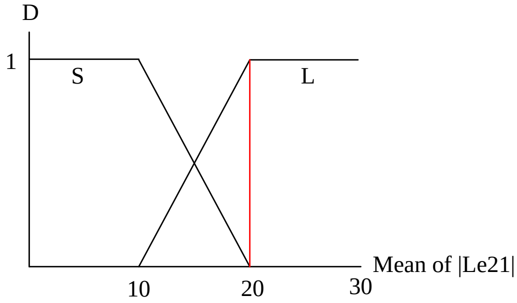

Fig. 5 EXIT membership function.

Iterative time's membership function, this is a decision iterative time's membership function. It is regarded as an output to decide the iteration times, and defined its relation variable denoted as T, and describes as following Fig. 6.

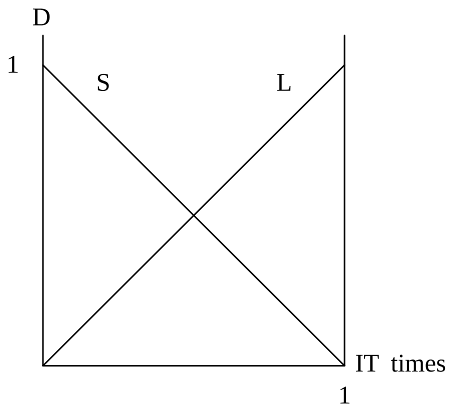

Fig. 6 Membership function of iterations

Fuzzy Rules exit four conditions which are:

If X is S and Y is S, then T is L.
If X is L and Y is S, then T is L.
If X is S and Y is L, then T is S.
If X is L and Y is L, then T is S.

Thus, the rule base of FLC(Fuzzy Logic Control) can be described as in Table 1.

Table 1 The rule base of FLC

Iteration times (T)		Mean of | Le21 | (Y) S	Mean of | Le21 | (Y) L
SNR(X)	S	L	S
	L	L	S

Fuzzy inference, the inferred result for the i-th rule can be obtained by Mamdami's minimum operation. E.g., if input SNR is 1.4 dB, and the mean of |Le21| is 20.then Dx = (0.8, 0.2), and Dy = (0, 1), so can trigger two rules,

R1: X = S = 0.8 and Y = L = 1, then T = S, gets Ts = min(0.8, 1) = 0.8.

R2: X = L = 0.2 and Y = L = 1, then T = S, gets Ts = min(0.2, 1) = 0.2.

So we can get the T_S = max(0.8, 0.2) = 0.8, and D_T = (0.8, 0).

The defuzzification process is to extract the crisp value that is the best representative of the inferred fuzzy result. In this application, the crisp control action is obtained by center of gravity. The defuzzified crisp result is applied to control the iteration to achieve a desire decoding goal. E.g., continues the above example D_T = (0.8, 0).

T = ┌(0.1*0.8 + 0.2*0.8 + 0.3*0.7 + 0.4*0.6 + 0.5*0.5 + 0.6*0.4 + 0.7*0.3 + 0.8*0.2+ 0.9*0.1 + 1*0) / (0.8 + 0.8 + 0.7 + 0.6 + 0.5+ 0.4 + 0.3 + 0.2 + 0.1 + 0) – 0.5 ┐
= ┌ 1.64 / 4.4 – 0.5 ┐
= ┌ -0.2 ┐
= 0 times.

IV. EXPERIMENTAL RESULTS

In this section, we conduct a series of experiments to illustrate the effectiveness of the bit-level correlation model we proposed for turbo decoding. In the simulation, the coded bits are modulated using binary phase shift keying (BPSK) and white Gaussian noise with a double-sided power spectral density of $N_0/2$ is added to the modulated signal.

In the next Fig. 7, the conventional Turbo decoding and the proposed fuzzy adaptive scheme decoding almost have the same as code gain as well. But in the iteration comparisons that are shown in Figure 8 indicates the proposed decoding scheme less than conventional Turbo decoding about 40%, and the final code gain is only degraded a little.

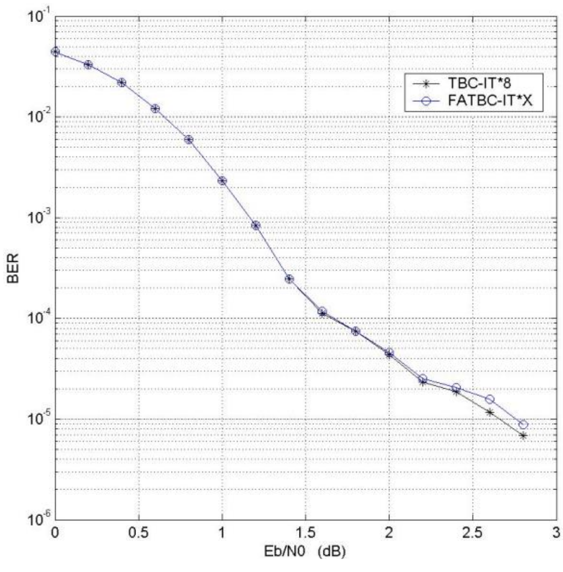

Fig. 7 The coding gain of the conventional vs. the proposal fuzzy adaptive Turbo decoding.

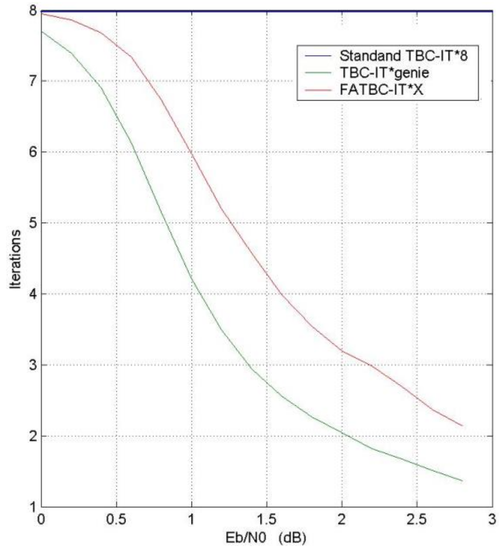

Fig. 8 The iteration comparisons of the proposed decoding scheme vs. the conventional Turbo decoding.

IV. CONCLUSIONS

A powerful channel coding – Turbo codes are widely used in 3G and 4G LTE wireless communication systems [7-8]. However, the usual decoder is unfit for real time data transmission, because of its large decoding delay. In this paper we propose a fuzzy adaptive scheme which can reduce the average iteration times about reducing down to half while no coding gain loss than that of conventional turbo decoders over an AWGN channels, but it needs an extra computation cost that of deciding whether processing a next decoding or not.

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