ABSTRACT
Turbo codes has better performance as the number of iteration and interleaver's size increases. This requires the delay and computational complexity for decoding an input data. In this paper, we propose an efficient method of decoding Turbo codes that can greatly reduce the iteration number with very low complexity. The MAP algorithm depends on the adjacent bits or received symbols. Therefore, to improve performance of MAP algorithm, the reliability of adjacent received symbols has to be guaranteed. Thus, we propose a simple ERS (Error Range Search) method for reliability of received symbols in MAP algorithm. Using the proposed ERS method, we analyze the performance of ERS/MAP algorithm and ERS/Turbo decoder in Rayleigh fading channel.

I. INTRODUCTION
Turbo codes were introduced in 1993 by Berrou, Glavieux and Thitimajshima [1]. Turbo Code is that the encoder is made up of two component codes, separated by an interleaver. These encoders have generally been RSC (Recursive Systematic Convolutional) codes, due to some suitable characteristics. Due to the interleaver, the two encoders are excited by two different input sequences, and thus need two separate decoders, these also being separated by interleavers. In original paper, they exhibited remarkable BER performance of $10^{-5}$ at an $E_b/N_0$ of 0.7 dB using only a 1/2 rate code, large interleaver size and sufficient number of decoding iteration [1]. Turbo codes have been a very active area of research for over five years. Currently, some of the communication systems (CDMA, TCM, Equalizer etc.) are beginning to apply principles of Turbo Codes and iterative decoding [3]. Recently, Turbo code is proposed to ITU as a candidate channel coding for higher rate transmission in IMT-2000 (International Mobile Telecommunication-2000). But in spite of the high performance and some applications, there are still remained problems such as increment of complexity by decoding computation, latency by interleaver and iterative decoding.

The decoders in a turbo decoder mainly use the MAP (Maximum a Posteriori) or SOVA (Soft Output Viterbi Algorithm). The MAP algorithm has been most commonly used in turbo codes because of high performance. At low Eb/No and high BER's, MAP algorithm can outperform SOVA by 0.5 dB or more. In contrast, the SOVA is offer slightly worse bit error performance but with reduced complexity when compared to the MAP algorithm [3]-[10]. Convolutional encoding process and its reverse process (MAP decoding) depend on the common adjacent bits or received symbols. Thus, we propose a simple ERS method for MAP algorithm and analyze the performance of MAP algorithm and Turbo codes in Rayleigh fading channel.

2. ITERATIVE DECODING OF MAP ALGORITHM AND TURBO CODES
The MAP algorithm performs decoding process to estimate the APP ($a$ posteriori probabilities) of the states and transitions of a Markov source observed through a discrete memoryless channel, was first presented by Bahl
et. al. in [2]. This yields the APP for each decoded bit and it is an optimal decoding method for linear codes which minimizes the bit error probability. The MAP algorithm was as applied to be used with Turbo codes in [1], but its structure was still complex. In [7], S. Pietrobon described the algorithm which made possible its hardware implementation.

For a single code, the MAP algorithm minimizes the symbol error probability. Therefore, after receiving $Y$, it is the job of the decoder to determine the most likely input bits, $d_i$'s, based on the received symbols. The log-likelihood ratio for the input symbol indexed at time $k$ is defined as

$$L(d_k) = \log \frac{P(d_k = 1 | Y)}{P(d_k = 0 | Y)}$$

(1)

In this expression, $P(d_i = i | Y)$ is the a posteriori probability of $d_k = i$ given knowledge of the received data $Y$. The decoder produces estimates, $d_k$'s, of the information bits based on the comparison of $L(d_k)$ to a threshold. For equiprobable input values over an AWGN channel, the estimator is given as

$$d_k = \begin{cases} 1 & \text{if } L(d_k) \geq 0 \\ 0 & \text{if } L(d_k) < 0 \end{cases}$$

(2)

In Turbo Codes, it is notable that the log-likelihood ratio has now decomposed into three components which can be represented as [3].

$$L(d_k) = L_{\text{systematic}} + L_{\text{apriori}} + L_{\text{extrinsic}}$$

(3)

The term $L_{\text{systematic}}$ is based only on the received systematic symbol at time $k$ and the term $L_{\text{apriori}}$ is based on the a priori information on the input bit $d_k$. For the decoding of a single convolutional encoder, the usual assumption is that of equiprobable input values which gives $L_{\text{apriori}} = 0$. The final term, which has been referred to as extrinsic information [1], is the new information pertaining to the input bit $d_k$. It is based on all parity and systematic information except the systematic value at time $k$. It is this decomposition of the log-likelihood ratio that will motivate the iterative turbo decoder and makes the MAP algorithm a very compatible decoding algorithm for turbo codes. Figure 1. shows the iterative decoding process of Turbo codes.

As mentioned above, to improve performance of MAP algorithm, the reliability of adjacent received symbols has to be guaranteed. However, MAP algorithm itself can't give it for any operation. Thus, we propose a simple ERS method for reliability of received symbols in MAP algorithm.

3. PROPOSED ERROR RANGE SEARCH METHOD

A block diagram of Turbo decoding by ERS method is presented in Figure 2. Also, Figure 3 gives an inner structure of the Error Range Search block.
Generally modulated signals are mixed with noise in channel, therefore it's hard to distinguish the original data. Most of decoding methods are that the mixed signals are entered to decoder and then decoding operation is initiated. But if we can estimate error-occurred-range and then give rather error-free data as input, we can expect some improvement of performance. In other words, in the error occurred range, noise-mixed data are used as MAP decoder input, and about the rest data, noise-removed data (Maximum value of soft data: 1 or -1) are used. Usually, there is no simple solution to estimate error-occurred range in convolutional coding. To achieve this, a simple error range search method based on the characteristic of inverse matrix in convolutional coding was presented in [12],[14-15]. The system model for the ERS (Error Range Search) /MAP decoder with eight-level soft decision decoding is shown in Figure 4.

The mathematical expression of the ERS algorithm procedure in Figure 4 can be explained as follows. We consider a rate half and constraint length (K) = 3 recursive systematic code. We define that the encoded sequence C(D) and generator matrix G(D) can be expressed as

$$X(D) = x_0 + x_1D + x_2D^2 + \cdots, \quad (4)$$

$$G(D) = \begin{pmatrix} 1 & G_{\mu}(D) \\ 1 & 0 \end{pmatrix} = \left( 1 - \frac{1 + D}{1 + D + D^2} \right) G_{\mu}(D) \quad (5)$$

$$Y(D) = X(D) \cdot G(D), \quad (6)$$

where Y(D) is the sequence of transmitted symbols which is due to the data encoding. Consider the sequence of received symbols R(D) with channel noise E(D) is given by

$$R(D) = \begin{pmatrix} R_n(D) \\ R_k(D) \end{pmatrix} = Y(D) + E(D), \quad (7)$$

and the received sequences R(D) are predecoded by an inverter circuit, to give the predecoded sequences U(D), where

$$U(D) = R(D) \cdot G^{-1}(D) = X(D) + E^*(D), \quad (8)$$

and $$E^*(D) = E(D) \cdot G^{-1}(D)$$. The predecoded error...
sequences $E^*(D)$ equals the first order extension of error in the ERS algorithm. In relation between the predecoded output $U(D)$ and channel error $E(D)$, the channel error $E(D)$ is extended to the first order convolutional error $E'(D)$ after predecoding operation $E(D)G^{-1}(D)$. The predecoded sequences $U(D)$ are then re-encoded by the same convolutional encoder used in the transmitter to give the re-encoded sequences $V(D)$ as follows.

$$V(D) = Y(D) + E^*(D),$$

where

$$E^*(D) = E^0(D) \cdot G(D),$$

and $E^*(D)$ is the second order extension of error in the ERS algorithm.

The re-encoded sequences $V(D)$ are added to the received sequences $R(D)$, to give the received error sequences

$$C(D) = R(D) + V(D) = E(D) + E^*(D).$$

The received error sequences $C(D)$ are erroneous terms remained only as shown in equation (11). Then, by the following operation the ERS algorithm is performed.

Table 1. Error Range Search Algorithm

<table>
<thead>
<tr>
<th>Algorithm 1</th>
<th>Error Range Search Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF $C(D) \neq 0$, i.e., $(E(D) + E^*(D) \neq 0)$ THEN</td>
<td></td>
</tr>
<tr>
<td>Error occurred range by error estimation reliability;</td>
<td></td>
</tr>
<tr>
<td>- $MSB_{correct} = MSB$</td>
<td></td>
</tr>
<tr>
<td>- $BIT_2_{correct} = BIT_2$</td>
<td></td>
</tr>
<tr>
<td>- $BIT_3_{correct} = BIT_3$</td>
<td></td>
</tr>
<tr>
<td>where BIT2 = noise-mixed data</td>
<td></td>
</tr>
<tr>
<td>ELSE Rest range;</td>
<td></td>
</tr>
<tr>
<td>- $MSB_{correct} = MSB$</td>
<td></td>
</tr>
<tr>
<td>- $BIT_2_{correct} = BIT_2 - error$</td>
<td></td>
</tr>
<tr>
<td>- $BIT_3_{correct} = BIT_3 - error$</td>
<td></td>
</tr>
<tr>
<td>where BIT2 - error, BIT3 - error = noise-removed data</td>
<td></td>
</tr>
<tr>
<td>$\rightarrow$ Go to the conventional MAP decoder</td>
<td></td>
</tr>
</tbody>
</table>

4. SIMULATION RESULTS

1. Performance of MAP algorithm and Turbo decoder by ERS in AWGN Channel

The BER results are plotted in figure 5. We here consider constraint length (K) of 3 and 5. Also, the length of frame is 192 bits and AWGN channel was considered in this simulation. From figure 5, we can clearly see the advantage of the proposed ERS method. Figure 5 shows the higher reliability and the better MAP decoding performance.

Figure 5. Performance of MAP algorithm by ERS method (R=1/2, K=3, 5, frame length =192 bits, AWGN)

We assumed that all errors are contained in the reliability range. For example, the reliability of 50% says that the range contained real-error-occurred location is the half of estimated range. From figure 5, we can conclude that the proposed ERS/MAP decoder gives an improvement of more than 0.5 dB over the classical MAP decoder in BER = $10^{-3}$.

The performances of Turbo codes by ERS method are plotted in figure 6. The reliability of ERS was about 45 ~ 55%. In Figure 6, when the 2 iteration was performed, the proposed ERS/iterative decoder has about over 0.7 dB extra coding gain in BER=$10^{-3}$, compared to the conventional iterative decoder.
2. Performance of Turbo decoder by ERS in Flat Rayleigh Fading Channel

In order to evaluate the performance of ERS/Turbo codes in a more realistic radio channel, we are also simulated in a flat Rayleigh fading channel. Simulations will consider rate-1/3 Turbo decoder using 4-state recursive convolutional code. Also, the results for the conventional Turbo codes are shown after 8 iterations, while ERS/Turbo codes are shown after 3 iterations. Regarding a BER of $10^{-3}$, the proposed ERS/Turbo decoder after 3 iterations has about 0.4 dB extra coding gain compared to the conventional Turbo decoder after 8 iterations.

5. CONCLUSION

In this paper, we analyzed the performance of MAP algorithm and Turbo Codes by ERS (Error Range Search) method. The MAP algorithm depends on the adjacent bits or received symbols. Therefore, to improve performance of MAP algorithm, the reliability of adjacent received symbols has to be guaranteed. Thus, we proposed a new ERS method for MAP algorithm in order to improve performance in turbo codes.

REFERENCES


BIography

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