Title	Near-Capacity-Achieving Simple BICM-ID
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Citation	2011 IEEE Communication Theory Workshop
Issue Date	2011-06-20
Type	Presentation
Text version	author
URL	http://hdl.handle.net/10119/9842
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Description	

Near-Capacity-Achieving Simple BICM-ID

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Abstract— **In this paper, a very simple close Shannon-limit achieving Bit-Interleaved Coded Modulation with Iterative Detection/Decoding (BICM-ID) system is proposed. The irregular repetition and single parity check codes, combined with partial accumulator and Extended Mapping (EM) are used. This paper also proposes EXIT-constraint Binary Switching Algorithm (EBSA) to determine optimal labeling patterns for allocating to each constellation point. With the proposed technique, the Extrinsic Information Transfer (EXIT) functions of the demapper and decoder curves can be closely matched. Furthermore, this paper combines the techniques described above together with modulation doping. It is shown through EXIT analysis that the demapper and decoder EXIT curves closely matched, and therefore, very near-capacity performance can be achieved. Bit Error Rate (BER) simulation results show that using our proposed technique, at a signal-noise ratio (SNR) point of only roughly 0.5dB away from the Shannon limit, clear threshold SNR happens, even though required complexity is very low; the complexity of the proposed technique is at an order of that required for a turbo code using memory-2 convolutional constituency codes.**

Keywords: BICM-ID, Irregular Repetition Code, Single Parity Check Code, Extended Mapping, Partial Accumulator, EXIT-constraint Binary Switching Algorithm, Modulation Doping.

I. INTRODUCTION

It has been recognized that Bit-Interleaved Coded Modulation with Iterative Detection /Decoding (BICM-ID) [1] is a bandwidth efficient coded modulation and transmission scheme, which is composed of a concatenation of an encoder and a bit-to-symbol mapper separated by a bit interleaver at the transmitter side. At the receiver side, the iterative processing is invoked, where extrinsic information is exchanged between the demapper and the decoder, according to the standard turbo principle.

Performance of the BICM-ID should be evaluated in terms of convergence and asymptotic properties [2] which can be expressed by the threshold signal-noise ratio (SNR) and bit error rate (BER) floor, respectively. Since BICM-ID is a serially concatenated system, its performance analysis can rely on the area property of the Extrinsic Information transfer (EXIT) chart [3]. Consequently, a design of transmission scheme based on BICM-ID can be considered as the matter of achieving good matching between the demapper and decoder EXIT curves. We have investigated several methods to minimize the gap between the two curves without requiring unacceptable complexity for demapping and decoding, while still keeping the tunnel open to achieve the threshold SNR as close to the Shannon limit and as low BER floor as possible.

Reference [4] proposes a very simple BICM-ID system in which single parity check and irregular repetition codes, combined with Extended Mapping (EM), are used. However, with this system, the gap between demapper and decoder curve is not still narrow enough. Moreover, it suffers from the error floor. This is in part because the degree allocation for variable nodes is not optimized, and in part the crossing point of the two curves EXIT is still not close enough to the (1.0, 1.0) Mutual Information (MI) point. In this paper, we first introduced the Linear Programming (LP) technique [5] for the degree allocation optimization, and then partial Accumulator (ACC) to lift the right most part of demapper EXIT curve up to (1.0, 1.0) MI point. With the proposed technique, the problems described above can be solved. Furthermore, we introduce a new technique, EXIT-constraint Binary Switching Algorithm (EBSA) combined with modulation doping. Simulation results show that using our proposed techniques, the signal-noise power ratio (SNR) threshold at only roughly 0.5dB away from the Shannon limit can be achieved, even though the required computational complexity for demapping and decoding with the proposed technique is only at an order of that required for a turbo code using memory-2 convolutional constituency codes.

II. SYSTEM MODEL

The schematic diagram of the proposed BICM-ID system is shown in Fig. 1.

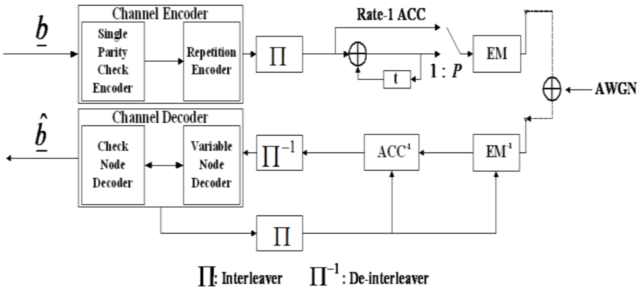

Fig. 1. System Model

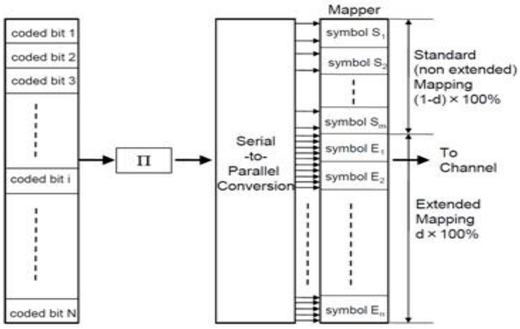

Fig. 2. Modulation Doping Technique

The binary bit information sequence ***b*** is encoded by channel encoder using single parity check, and irregular repetition codes. The encoded bit sequence is bit-interleaved by an interleaver (Π), accumulated by ACC, and then mapped on to one of the constellation points, where extended mapping rules are mixed, as indicated in Fig. 2 [7]. The symbols are transmitted over an Additive White Gaussian Noise (AWGN) channel. At the receiver, the discrete time description of the received symbol *y (k)* is expressed by

$$y(k) = x(k) + n(k), \tag{1}$$

where, with k being the symbol timing index, $x(k)$ is the transmitted modulated symbol with unit power, and $n(k)$ the zero mean complex AWGN component with variance σ_N^2. Iterative demapping and decoding takes place at the receiver, where extrinsic information is exchanged between the demapper and decoder, according to the standard turbo principle.

The demapper calculates from the received signal point *y(k)*, corrupted by AWGN, the extrinsic LLR of the μ^{th} bit in the symbol transmitted at the k^{th} symbol timing, by

$$L_e[b_\mu(k)] = \ln \frac{\sum_{s\in S_0} e^{(-\frac{|y-s|^2}{\sigma_N^2})} \prod_{v=1,v\neq\mu}^{l_{map}} e^{(-b_v(s)L_a(b_v(s)))}}{\sum_{s\in S_1} e^{(-\frac{|y-s|^2}{\sigma_N^2})} \prod_{v=1,v\neq\mu}^{l_{map}} e^{(-b_v(s)L_a(b_v(s)))}} \tag{2}$$

where s denotes a signal point in the constellation, *S0(S1)* indicates the set of the labels having the μ^{th} bit being 0(1), and $L_a(b_v(s))$ the a priori LLR fed back from the decoder corresponding to the v^{th} position in the label allocated to the signal point *s*.

Because of the space limitation, details about the decoding process are not provided in this extended abstracts. If this paper is accepted, those details will be presented in poster.

III. EXIT-CONSTRAINT BINARY SWITCHING AGORITHM

The design of labeling pattern is, in general, aiming to push up the right most part of the demapper curve to as high point as possible. To achieve this goal, Bit Switching Algorithm (BSA) is proposed by [7]. However, BSA takes into account neither (A) the shape of the EXIT curve in the MI ranges of less than one, nor (B) the matching with the decoder curve. To solve the problem (A) described above, adaptive BSA (ABSA) is proposed in [8]. However, still there is a possibility that the two curves intersect because of the problem (B). To solve this problem, we propose a new technique to achieve the optimal labeling pattern.

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Initialize the weight coefficient vector $\boldsymbol{\lambda} = [\lambda_0 \ldots \lambda_{lamp-1}] = [0 \ldots 1]$;
Initialize the desirable vertical epsilon values. e.g., $\varepsilon^v = [0.001][1, \ldots, N]$.
repeat
    for i = 1 to 100 do
        Randomly generate labeling pattern.
        Perform BSA.
    end for
    Select the labeling pattern with minimum cost from BSA.
    Perform LP to determine the optimal node degree allocation.
    Draw demapper EXIT curve and LP-based decoder EXIT curve and evaluate the horizontal gap ($\varepsilon^h$) [5] between this two curves.
    if the gap around $Z_{ap}$ is larger than initialized epsilon ($\varepsilon^v$) then
        $\lambda_{ap} = \lambda_{ap} - 1$,    $0 < ap < l_{map}-1$
    end if
until the minimum gap is obtained
```

Table 1. EBSA algorithm

A. Cost Calculation

For the number of bit-per-symbol l_{map} and the number l_{ap} of known a priori information bit given, where $l_{ap} = 0, 1, \ldots, l_{map} - 1$, the labeling cost Z_{lap-1} can be expressed as,

$$Z_{l_{ap}-1} = \frac{1}{l_{map} 2^{l_{map}-1} 2^{l_{map}-l_{ap}-1}} \sum_{v=1}^{l_{map}} \sum_{s|s_v=0} \sum_{\hat{s}|\hat{s}_v=1} e^{(-SNR\cdot|\mu(s_v)-\mu(\hat{s}_v)|^2)} \tag{3}$$

Since Z_{lap-1} can be decomposed into symbol wise cost Z^h_{lap-1}, it can also be expressed as,

$$Z_{l_{ap}-1} = \sum_{h=0}^{2^{l_{map}}-1} Z^h_{l_{map}} \tag{4}$$

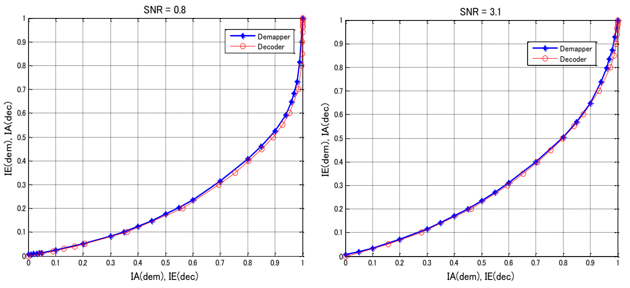
with

$$Z^h_{l_{map}} = \frac{1}{l_{map} 2^{l_{map}-1} 2^{l_{map}-l_{ap}-1}} \sum_{v=1}^{l_{map}} \sum_{s^h|s^h_v=0} \sum_{\hat{s}^h|\hat{s}^h_v=1} e^{(-SNR|\cdot\mu(s^h_v)-\mu(\hat{s}^h_v)|^2)} \tag{5}$$

Because l_{ap} takes a number of 0, 1… l_{map} -1, the cost values make impact on the shape of the demapper EXIT curve. The total cost can be calculated as,

$$Z_t = Z \cdot \lambda^t \tag{6}$$

where vector $\boldsymbol{Z} = [Z_0 \ldots Z_{lmap-1}]$ denote the costs correspending to the case from no a priori information is known to the case that perfect a priori information is known, and $\lambda^t = [\lambda_0 \ldots \lambda_{lmap-1}]$ denotes the weight coefficient vector.

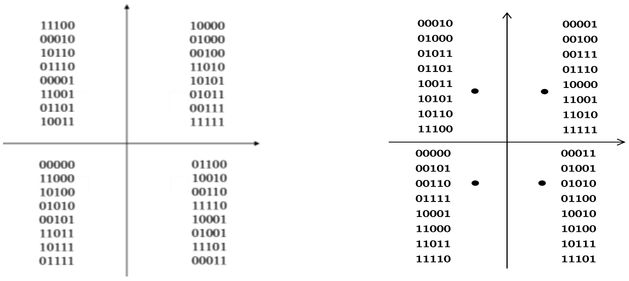


(a) (b)

Fig 3. EXIT chart (a) for SNR = 1.0dB, (b) for 3.1dB

B. *EXIT-constraint Binary Switching Agorithm (EBSA)*

Using the cost values defined above, this paper proposes the EXIT-constraint Binary Switching Algorithm (EBSA), which is expressed in Table 1. The labeling patterns in Fig. 4 (a) and (b) are obtained by using the proposed algorithm. The weight coefficient vector λ determines which parts of the demapper EXIT curve should be more pushed down than the other parts. To check the gap, we evaluate the vertical distances ε^{v} at each pre-defined EXIT constraint point between the two curves in the EBSA algorithm summarized in Table 1. It should be emphasized that the LP-based weight optimization is included in the EBSA itself, and thereby also the optimal node degree allocation makes influence on the cost Z_{lmap-1}.



(a) (b)

Fig. 4. (a) Labeling Pattern Optimized at SNR = 1dB, (b) at 3.1dB.

IV. NUMERICAL RESULTS

A series of computer simulation was conducted to evaluate the performance and the convergence property of the proposed technique. To obtain reliable enough results, we transmitted 100 blocks, each having more than 10,000 information bits.

Fig. 3 (a) and (b) show the EXIT charts for the codes and mapping rules obtained by using the proposed techniques for SNR = 1.0dB and 3.1dB, respectively. It is found that the demapper and decoder EXIT curves are exactly matched each other. Fig. 5 shows their BER performances.

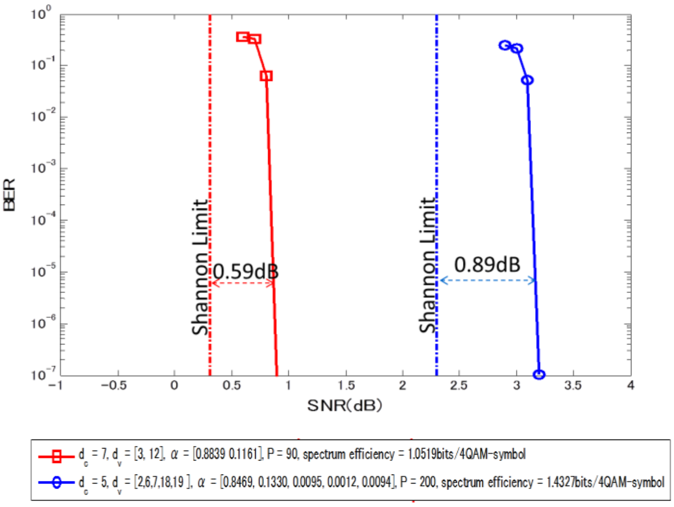


Fig. 5. BER performances

V. CONCLUSIONS

This paper has proposed the EBSA technique combined with modulation doping for BICM-ID with a single parity check and irregular repetition codes. The results show that a clear turbo-cliff, corresponding to the threshold SNR, is achievable roughly only 0.5dB away from the Shannon limit for a spectrum efficiency of 1.0519 bit per 4-QAM symbol.

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