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► **To cite this version:**

Salim Haddad, Amer Baghdadi, Michel Jezequel. Convergence and Complexity Analysis of Turbo Demodulation with Turbo Decoding. Colloque national du groupe de recherches System On Chip - System In Package (SOC-SIP), Jun 2012, Paris, France. hal-00725058

HAL Id: hal-00725058

<https://hal.science/hal-00725058>

Submitted on 23 Aug 2012

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Convergence and Complexity Analysis of Turbo Demodulation with Turbo Decoding

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I. INTRODUCTION

Advanced wireless communication standards impose the use of modern techniques to improve spectral efficiency and reliability. Among these techniques, Bit-Interleaved Coded Modulation (BICM) with different modulation orders and Turbo Codes with various code rates are frequently adopted. The BICM principle currently represents the state-of-the-art in coded modulations over fading channels. The BICM with Iterative Demapping (BICM-ID) scheme is based on BICM with additional soft feedback from the Soft-Input Soft-Output (SISO) channel decoder to the constellation demapper.

In this context, several techniques and configurations have been explored. When the convolutional code classically used in BICM-ID schemes was replaced by a turbo code, only a small gain of 0.1 dB was observed. This result makes BICM-ID with turbo-like coding solutions (TBICM-ID) unsatisfactory with respect to the added decoding complexity.

On the other hand, Signal Space Diversity (SSD) technique, which consists of a rotation of the constellation followed by a signal space component interleaving, has been recently proposed. It increases the diversity order of a communication system without using extra bandwidth.

Combining SSD technique with TBICM-ID at the receiver side has shown excellent error rate performance results particularly in severe channel conditions (erasure, multipath, real fading models) [1][2]. These results were behind the adoption of this system in DVB-T2 standard (using LDPC channel code). The TBICM and TBICM-ID modes applying the SSD technique are denoted by TBICM-SSD and TBICM-ID-SSD.

Nevertheless, most of the existing works have not considered these techniques from an implementation perspective. In fact, the application of the iterative demapping in future receivers integrating advanced iterative channel decoding will lead to further latency problems, more power consumption and more complexity caused by feedbacks inner and outer the decoder. Besides extrinsic information exchange inside the iterative channel decoder, additional extrinsic information is fed back as *a priori* information used by the demapper to improve the symbol-to-bit conversion. The number of iterations to be run at each level should be determined accurately as it impacts significantly error rate performance, latency, power consumption, and complexity.

This work considers the implementation efficiency of iterative receivers based on turbo demodulation and turbo decoding in order to achieve gain in band-limited wireless communication systems. Convergence speed is analyzed for various system configurations to determine the exact required number of iterations at each level. Significant complexity reductions in terms of arithmetic operations and memory accesses can be achieved by means of the proposed original iteration scheduling [3]. In fact, this complexity reduction improves proportionally latency and power consumption, and thus paves the way towards the adoption of TBICM-ID-SSD hardware implementations in future wireless receivers.

A. System Model

The considered system uses one transmit and one receive antenna while assuming perfect synchronization. Fig. 1 shows a basic transmitter and receiver model using turbo demodulation and decoding. We denote by TBICM-ID-SSD a turbo BICM with iterative demapping coupled with signal space diversity.

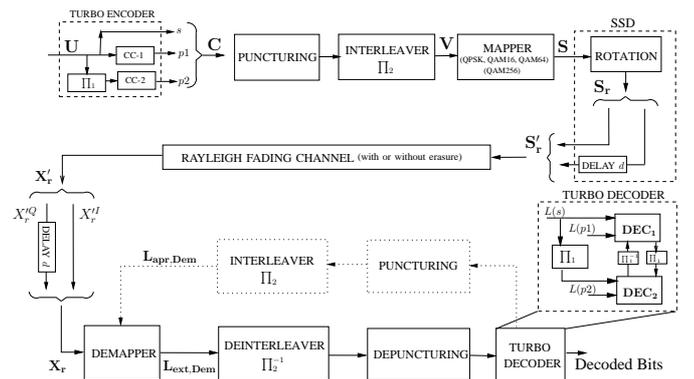


Figure 1. System model with TBICM-ID-SSD.

On the transmitter side, information bits U which are called systematic bits are regrouped into symbols u_p consisting of l bits, and encoded with an l -binary turbo encoder. It consists of a parallel concatenation of two identical convolutional codes (PCCC). The output codeword C is then punctured to reach a desired coding rate R_c . The 8-state double binary ($l = 2$) recursive systematic convolutional code (RSC code), adopted in the WiMax standard, is considered for the turbo encoder.

Modulation scheme	CASE1 (With recomputed Euclidean distances)						CASE2 (With stored Euclidean distances)					
	$R_c = 1/2$			$R_c = 6/7$			$R_c = 1/2$			$R_c = 6/7$		
	Complexity Reduction			Complexity Reduction			Complexity Reduction			Complexity Reduction		
	<i>arith</i>	<i>load</i>	<i>store</i>	<i>arith</i>	<i>load</i>	<i>store</i>	<i>arith</i>	<i>load</i>	<i>store</i>	<i>arith</i>	<i>load</i>	<i>store</i>
QPSK	19.9%	12.8%	3.7%	15.4%	8.9%	2.2%	2.7%	11.5%	3.4%	1.8%	7.9%	2.1%
QAM16	25.8%	16.9%	3.7%	22.2%	12.5%	2.2%	10.8%	17.5%	3.1%	8.1%	13%	2%
QAM64	30.4%	24.4%	3.7%	28.6%	20.5%	2.2%	19.2%	25.4%	2.5%	16.9%	21.5%	1.7%
QAM256	32.4%	29.9%	3.7%	31.7%	27.8%	2.2%	24.2%	30.7%	1.5%	23.2%	28.7%	1.2%

Table I
REDUCTION IN NUMBER OF OPERATIONS, READ/WRITE ACCESS MEMORY COMPARING "4IDem_2EIDec" TO "6IDem" FOR DIFFERENT MODULATION SCHEMES AND CODE RATES.

In order to gain resilience against error bursts, the resulting sequence is interleaved using an S -random interleaver Π_2 . Punctured and interleaved bits denoted by V are then gray mapped to channel symbols s_q chosen from a 2^M -ary constellation X , M is the number of bits per modulated symbol. Finally the SSD technique is applied.

II. TBICM-SSD AND TBICM-ID-SSD CONVERGENCE ANALYSIS

Constellation rotation and bits-to-symbol allocation scheme (bit protection) impact considerably the convergence speed. Convergence speed designates the rapidity of the convergence of the iterative process. Both TBICM-SSD and TBICM-ID-SSD system configurations are considered. Extrinsic information transfer (EXIT) charts are used for a clear and thorough analysis of the convergence speed. Since this EXIT chart analysis is asymptotic, infinite long BICM interleaver size is assumed.

Analyzing EXIT chart curves shows optimized profile iterations by applying one turbo code iteration for each demapping iteration. Note that after the third demapping iteration, only a slight improvement in convergence is predicted. This result can be used to reduce the number of demapping iterations. The EXIT tunnel is wider for the rotated case than the one without. Moreover, the tunnel is limited to one turbo demapping iteration for the latter case. Thus, making demapping iterations will not affect the convergence speed. However the tunnel is enlarging (improving) until three demapping iterations using rotated constellation.

III. RESULTS

Various constructed EXIT charts show that after a specific number of demapping iterations, only a slight improvement is predicted. Iterations begin to coincide with each other. This result can be used to reduce the number of demapping iterations without affecting error rates, while keeping the same total number of turbo decoding iterations. For each demapping iteration, one turbo code iteration is applied. Reducing the number of turbo demapping iterations will reduce the total number of iterations for the turbo decoder. To keep the same number of iterations for the decoder, one turbo code iteration is added at the last iteration of the demapper for each one eliminated. Reducing the number of demapping iterations will reduce the latency and the complexity in means of total number of operations needed. An accurate evaluation of the complexity in terms of number

and type of arithmetic operations and memory access has been conducted. In addition, a complexity normalization technique has been proposed [3] towards a fair comparison between the two modes (TBICM-SSD and TBICM-ID-SSD).

Using this normalized complexity technique, achieved complexity reduction ratios comparing 4 demapping iterations with 2 extra decoding iterations at the last iteration of the demapper (4IDem_2EIDec) to 6 demapping iterations (6IDem) for all configurations are summarized in Table I.

Results have shown that, with the proposed iteration scheduling, the number of normalized arithmetic operations is reduced from 15.4% for QPSK configuration up to 32.4% for QAM256 for CASE 1 where the Euclidean distances are recomputed for each demapping iteration. Similarly, the number of read access memory is reduced in a range between 8.9% to 29.9. Furthermore, the number of write access memory is reduced in a range between 1% and 4%. On the other hand, a maximum loss of 0.15 dB is shown for all modulation schemes and code rates in a fast-fading channel with and without erasure [3].

IV. CONCLUSION

Convergence speed analysis is crucial in TBICM-ID-SSD systems in order to tune the number of iterations when considering the practical implementation perspectives. Conducted analysis has demonstrated that omitting two turbo demodulation iterations without decreasing the total number of turbo decoding iterations leads to promising complexity reductions while keeping error rate performance almost unaltered.

In the same context, promising results have been recently obtained when considering a feedback loop to the SISO equalizer for MIMO systems. Future work targets the extension of this analysis to other base-band iterative applications and its integration into available hardware prototypes.

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