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Mapping Optimisation for turbo-equalization improved by iterative demapping

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Abstract: A design rule for mapping optimisation adapted to the turbo-equalization improved by iterative demapping is presented. We demonstrate that thanks to a carefully designed mapping, different to the classical Gray mapping, Bit Error Rate (BER) performance is improved for a frequency selective channel.

Introduction: Turbo-equalization is a receiving process performing iteratively equalization and channel decoding for frequency-selective channels. Soft information generated by each receiving function is improved through the iterations until the optimum behaviour of the system is reached. In the studied system the equalization part is based on adaptive filtering as proposed in [1]. In the context of Bit Interleaved Coded Modulation (BICM), the iterative demapping is an iterative process between the soft demapping device, which converts complex symbols into Log Likelihood Ratios (LLR) on bits, and the channel decoding [2]. In this Letter, we propose a mapping optimisation for the turbo-equalization improved by the iterative demapping presented in [3] and validate the design rule by simulation results for a 16QAM modulation.

Turbo-equalization improved by iterative demapping: At the transmitter, binary data b_n is coded by a convolutional code of polynomial generator $(5,7)_0$ and rate $\frac{1}{2}$. After bit-interleaving each quadruplet of coded bits $C_n = (c_n^0, c_n^1, c_n^2, c_n^3)$ is mapped to a complex symbol $d_n = \mu(C_n)$ chosen from the 16QAM constellation $X = (s_1, \dots, s_{16})$ according to the mapping μ .

The received symbols are expressed as $r_n = \sum_{k=0}^{L-1} h_k d_{n-k} + w_n$ where h_k are the taps of the discrete equivalent channel impulse response of length L , and w_n is an additive white gaussian noise of single-sided power spectral density N_0 .

Turbo-equalization is an iterative process that consists of several modules. Each module principally contains a filtering based equalizer adapted by a Least Mean Square (LMS) algorithm and a channel decoder. The first equalizer is a Decision Feedback Equalizer (DFE).

Fig. 1 depicts one module of turbo-equalization associated with iterative demapping from the second iteration; the Inter Symbol Interference (ISI) Canceller (IC) processes the complex symbol estimates \bar{d}_n^p where p is the iteration number, and the channel symbols r_n [1].

Before the decoder based on the Soft Output Viterbi Algorithm, a soft demapper converts the equalized symbols \hat{d}_n into LLRs on encoded bit c_n^i given by

$$\Lambda(c_n^i | \hat{d}_n) = \log \frac{P(c_n^i = 0 | \hat{d}_n)}{P(c_n^i = 1 | \hat{d}_n)} = \log \frac{\sum_{d_n \in X_1^i} p(\hat{d}_n | d_n) P(d_n)}{\sum_{d_n \in X_0^i} p(\hat{d}_n | d_n) P(d_n)} \quad (1)$$

where X_b^i is the subset of X for which $c_n^i = b$.

In classical turbo-equalization $P(d_n)$ is constant and equal to $1/16$. The principle of the iterative demapping based on bit interleaving is to use the *a priori* probability on bits produced by the decoder at the previous iteration. Under the assumption that the coded bits are independent (perfect bit interleaving), the *a priori* probability on each symbol, for $m = 1, \dots, 16$ and $s_m = \mu(q_m^0, q_m^1, q_m^2, q_m^3)$, can be calculated as

$$P(d_n = s_m) = \prod_{i=0}^3 P(c_n^i = q_m^i) \quad (2)$$

Thus in iterative demapping the LLR including the *a priori* LLR $\Lambda^{apriori}(c_n^i)$ and the extrinsic LLR $\Lambda^{ext}(c_n^i)$ is given by:

$$\Lambda\left(c_n^i | \hat{d}_n, \{c_n^j\}_{j=0, \dots, 3}^{apriori}\right) = \log \frac{\sum_{d_n \in X_1^i} p(\hat{d}_n | d_n) \prod_{j=0; j \neq i}^3 P(c_n^j)}{\sum_{d_n \in X_0^i} p(\hat{d}_n | d_n) \prod_{j=0; j \neq i}^3 P(c_n^j)} + \Lambda^{apriori}(c_n^i) \quad (3)$$

$$\underbrace{\hspace{10em}}_{\Lambda^{ext}(c_n^i)}$$

As in turbo-decoding [5], only $\Lambda^{ext}(c_n^i)$ is provided to the decoder. Before decoding a bit deinterleaver permutes the LLRs to decorrelate them. Similarly, a bit interleaver followed by a soft conversion LLRs on bits into complex symbols is performed after decoding to produce the new symbol estimates \bar{d}_n^{p+1} .

As the IC can totally cancel the ISI, the optimum performance of turbo-equalization for fixed channels corresponds to the BICM over AWGN channel [4].

Mapping optimisation: Thanks to appropriate mappings the iterative demapping can easily outperform the BICM reference system with Gray mapping [2]. Ten Brink proposes to characterise each mapping with the help of I_0 , the Mean Average Bit-wise Mutual (MABM) information conditioned to ‘no other bit known’, defined as

$$I_0 = \frac{1}{4} \sum_{i=0}^3 I(\Lambda(c_n^i | \hat{d}_n) | c_n^i) \quad (4)$$

where $I(\lambda | c_n^i) = \frac{1}{2} \sum_{c_n^i=0,1} \int_{-\infty}^{+\infty} p(\lambda | c_n^i) \times \log_2 \frac{2 \cdot p(\lambda | c_n^i)}{p(\lambda | c_n^i = 0) + p(\lambda | c_n^i = 1)}$.

We adapt this parameter to a turbo-equalization scheme and also use the parameter I_{all} , the MABM information conditioned to ‘all bits $\{c_n^i\}_{i=0,\dots,3}^{apriori}$ known’, defined as

$$I_{all} = \frac{1}{4} \sum_{i=0}^3 I(\Lambda^{ext}(c_n^i) | c_n^i) \quad (5)$$

The probability density function of the extrinsic LLR $p(\Lambda^{ext}(c_n^i) | c_n^i)$ is evaluated through a histogram at the output of the demapper. For turbo-equalization I_0 is calculated at the first iteration after the DFE: no bits are known. Thus it is linked up with the performance of the first iteration and with the trigger point of the iterative process. I_{all}

corresponds to the ideal case of error free feedback (all bits known, IC optimum). We create a set of random mappings characterized by their couple (I_0, I_{all}) at $E_b / N_0 = 6dB$. We simulate ‘Proakis A’ channel whose taps are $\{h_k\} = [0.04; -0.05; 0.07; -0.21; -0.5; 0.72; 0.36; 0; 0.21; 0.03; 0.07]$.

Fig. 2 presents the results for eight different mappings. The Gray mapping, n° 8, has the highest I_0 but the lowest I_{all} . Indeed the Gray mapping exhibits the best performance for non iterative BICM systems, but as explained in [2] it brings no gain for iterative demapping. Thus, the gain between I_0 and I_{all} for the Gray mapping in improved turbo-equalization is only due to the cancellation of ISI and not due to iterative demapping. Moreover the achievable gain for a given mapping is represented by the difference between I_{all} of the Gray mapping and I_{all} of the given mapping. To select the best mapping a compromise is necessary. Indeed a high I_{all} leads to very good BER performance of the system but it corresponds also to a low I_0 , which determines the BER performance of the first iteration. For low I_0 the performance of the first iteration of turbo-equalization is extremely degraded leading to an improvement of BER performance only for very high SNR. So we choose the mapping 4 which has a medium I_0 and a I_{all} not too close to the Gray mapping I_{all} .

Simulation results and conclusion: Fig. 3 presents the BER performance of improved turbo-equalization with the mapping 4 on the "Proakis A" channel. The AWGN Gray curve is a benchmark as it represents the optimum performance of the classical turbo-equalization scheme with Gray mapping. The improved turbo-equalization should converge towards the ‘IC opti, ID opti’ curve which represents the performance of an

error free feedback at the IC and at the demapper. The improved turbo-equalization, associated with mapping 4, exhibits a significant gain of 1.6dB over the classical turbo-equalization, with Gray mapping scheme at a BER of 10^{-4} .

We demonstrate that, thanks to iterative demapping and a carefully designed mapping, with the help of I_0 and I_{all} , a significant gain on the BER performance can be reached compared to the classical turbo-equalization scheme.

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Figure captions :

Fig.1 Module p+1 of turbo-equalization improved by iterative demapping

Fig.2 Evolution of I_0 and I_{all} for different mappings at $E_b/N_0 = 6dB$.

Fig.3 BER performance of improved turbo-equalization with mapping 4.

Figure 1

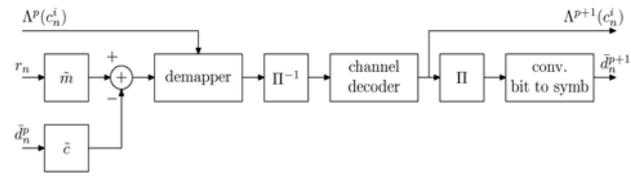


Figure 2

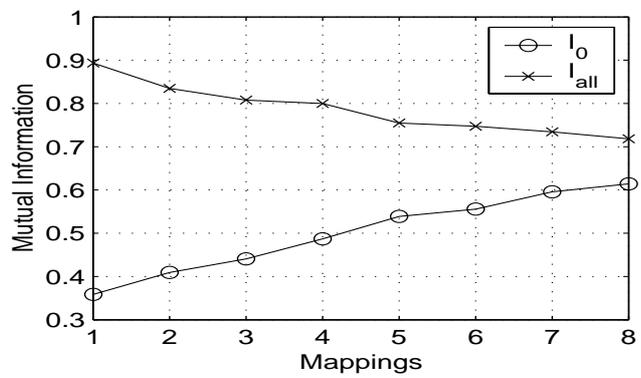


Figure 3

