HYBRID AUTOMATIC REPEAT REQUEST SCHEME WITH TURBO CODES

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ABSTRACT

A novel hybrid automatic repeat request system based on turbo codes, called turbo HARQ system, is proposed. The iterative turbo decoding procedure is exploited to request retransmission of not decodable blocks without the necessity of an outer error–detecting code. It is shown that the turbo HARQ scheme with code rate $R_c = 1/2$ and interleaver length 1024 significantly outperforms the classical turbo coding scheme — especially for low SNR — without essential loss in throughput.

1 INTRODUCTION

Automatic repeat request (ARQ) protocols are well-known methods to achieve high reliability in digital transmission schemes. The information is protected by an error-detecting block code. If the decoder detects an erroneous transmitted block, retransmission of this block is requested via a feedback channel which is assumed to be error-free throughout this paper. Additionally, the request is assumed to be repeated until the decoder detects error-free transmission. The great advantage of such selective repeat ARQ schemes is to provide a very low error rate with a decoder of low complexity. An important drawback of ARQ transmission systems is a substantially decreased throughput due to a large number of retransmissions for low signal-to-noise ratio (SNR). Therefore, transmission systems where ARQ protocols are combined with forward error correction (FEC), named hybrid-ARQ (HARQ) [1], are employed. Here, block error probability as well as the resulting number of repetition requests is substantially decreased by FEC capabilities.

Former work on HARQ systems deals with the application of multiple error correcting codes [1, 2, 3]. Recently, the employment of turbo codes [4, 5] for FEC and CRC codes for error detection in a HARQ transmission system was proposed in [6].

In this paper, the application of turbo codes to HARQ systems for both, error detection and error correction, is presented. The proposed scheme exploits the properties of the iterative turbo decoding scheme to detect erroneous blocks with high reliability. It is shown that especially for low to moderate SNR, the turbo HARQ system significantly outperforms the classical turbo coding scheme without essential loss in throughput.

The organization of the paper is as follows. In Section 2 a short introduction to turbo coding and decoding is given. The important properties of iterative turbo decoding for the application to HARQ systems are derived. In Section 3 the novel turbo HARQ system is presented, where the retransmission request is exclusively indicated by properties of the iterative turbo decoding. Simulation results in Section 4 show the performance of the proposed scheme. Section 5 concludes this paper.

2 PROPERTIES OF ITERATIVE TURBO DECODING

The turbo coding scheme consists of a parallel concatenation of two or more systematic constituent codes. Usually, two identical convolutional codes are chosen as constituents. The input of the constituent encoders are linked together by an interleaver. By puncturing of parity symbols from the constituent encoder outputs, the code rate can be adjusted very fine, cf. [7]. For moderate to large code length, turbo codes with pseudo random interleaver shows best performance close to the Shannon limit, as long as the desired BER is not substantially
Maximum likelihood decoding of turbo codes is not feasible due to interleaving. Therefore, Berrou et al. [4, 5] proposed an iterative decoding scheme for turbo codes with relative low complexity, which seems to be “near maximum likelihood”. It requires soft-in/soft-out constituent decoders. Iteratively, each constituent code is decoded individually using channel information of the systematic code word part and of the parity code word part belonging to this constituent code. Channel information of punctured parity symbols is inserted in such a way that the transition probabilities are equal for both binary symbols. Additional to the channel information, each constituent decoder takes into account extrinsic information of the data symbols generated by the other decoder. Feeding forward extrinsic information is the key point in turbo decoding. Extrinsic information represents reliability information of a data symbol exclusively due to the channel information as well as the a-priori information of all other code symbols and the constraints of the constituent code. In the subsequent decoding of the other constituent code extrinsic information is used as a-priori information on the data symbols. The iteration stops if a given number of decoding steps is reached or a specified criterion indicates sufficient reliability of the decoding decision, cf. [8, 9]. Thereby, decoding step means the individual decoding procedure for one constituent code.

In [9], the stability of iterative turbo decoding is discussed. It is stated that the number of bit errors in the current data block versus the number of decoding steps typically shows three different courses, see Fig. 1:

- Type “A”: The iterative decoding procedure converges fast to a stable state, where the decoding decision remains constant for further decoding steps. Typically, there are no or only a few bit errors in the current data block.

- Type “B”: The iterative decoding does not converge to a stable state, it diverges. The decoding decision changes with every decoding step. The number of errors remains relatively large for all decoding steps.

- Type “C”: The iterative decoding does not converge to a stable state. The number of bit errors extremely oscillates during the decoding procedure. Thereby, the maximum bit error rate may be up to 25% whereas the minimum bit error rate goes to zero.

In order to classify a received block into type A, B, or C, several criterions were derived in [9]. If the decoding decision remains constant within 3 subsequent decoding steps, the iterative decoding is assumed to have converged. Hence the current block is classified into type A. Otherwise the Hamming distance between subsequent decoding decisions is exploited to distinguish between type B and C, see [9]. This method to separate received blocks into stable and unstable blocks is very useful for the application of turbo codes to hybrid ARQ systems.

It can be observed that especially for low to moderate SNR the unstable blocks of type B or C predominate the performance of the turbo decoding scheme. Usually, for unstable blocks the decoding decision is taken at the last decoding step. Therefore, taking the decoding decision at the decoding step with the minimum number of errors instead, can substantially decrease the error rate, especially for blocks of type C, see also Fig. 1. An efficient and reliable method to estimate a decoding step with a relatively small number of errors is presented in [9].

The properties of the iterative turbo decoding scheme described in this section are well suited to apply turbo codes to efficient HARQ transmission systems.

3 TURBO HYBRID–ARQ SYSTEM

Usually, in hybrid ARQ systems the error-detecting outer block code of the ARQ protocol is combined with an inner powerful code to decrease the average number of retransmission requests. In this section, a turbo hybrid ARQ transmission system is presented, where the retransmission request is exclusively indicated by properties of the iterative turbo decoding, see Section 2.

If the received block is classified into a block of type A, the iterative decoding is assumed to have converged to a stable state, and there are no or only a few bit errors. Therefore, retransmission for blocks of type A is not necessary. In a turbo hybrid ARQ system, called turbo HARQ system, retransmission is only requested if the received block is classified into a block of type B or C. For these blocks the iterative decoding show an unstable behavior and the average number of bit errors at the last decoding step is relatively high, see Section 2. Please note that the method to distinguish between stable and unstable blocks, presented in Section 2, is
quite simple and the additional effort for this detection is negligible.

Obviously, every retransmission request of an ARQ scheme decreases the throughput of the scheme. Hence, it is possible to decrease the number of retransmission requests, the effective throughput is increased. For blocks of type C, it is possible to achieve a very low bit error rate if the decoding decision is taken at the decoding step with the minimum number of errors, see Section 2. Therefore, we propose an alternative hybrid ARQ system with turbo codes, called turbo HARQ scheme, where retransmission is only requested for received blocks of type B. For received blocks of type C, the decoding step with the minimum number of bit errors is estimated acc. to [9] and the decoding decision is taken at this decoding step.

4 SIMULATION RESULTS

Unfortunately, there exists no reliable analytical method to estimate the performance of turbo codes and the frequency of occurrence of unstable blocks up to now. The only feasible way to state the performance of the proposed turbo HARQ system is to perform computer simulations.

Firstly, a turbo HARQ system with code rate \( R_c = 1/2 \) and transmission over the AWGN channel using BPSK is investigated. The turbo code consist of two identical recursive, systematic 16-state convolutional codes with rate 1/2 and a pseudo random interleaver of length 1024. The generator matrix of each constituent code reads \( (1, (1 + D^2 + D^3 + D^4)/(1 + D + D^4)) \). Puncturing of the constituent encoder output symbols is done acc. to [4]. For soft-in/soft-out decoding of the constituent codes the algorithm of Bahl et al. [10] is employed. The maximum number of decoding steps is restricted to 40, i.e. the maximum number of iterations is 20. The selective ARQ protocol with an unlimited number of repeated transmissions is used. The resulting throughput and the achieved BER are plotted in Fig. 2. Since the usual abscissa parameter \( E_b/N_0 \) depends on the throughput of the scheme, here, the abscissa is labeled by \( E_s/N_0 \), where \( E_s \) is the average energy per transmitted symbol and \( N_0 \) the one-sided noise power density.

It can be observed that with the proposed turbo HARQ scheme reliable transmission with BER \( < 10^{-5} \) is possible for \( E_s/N_0 > -3 \) dB. However, for \( E_s/N_0 < -2 \) dB the number of retransmitted blocks increases rapidly and the resulting throughput becomes extremely low. In the range \(-2 \) dB \( < E_s/N_0 < -1 \) dB the turbo HARQ system shows significantly better performance than the classical turbo coding scheme with substantial loss in throughput. Additionally, in the investigated range of SNR the proposed scheme outperforms the improved turbo coding scheme with indication of the decoding step with the minimum number of errors acc. to [9]. A comparison to competing HARQ systems with similar code rates, which were presented in [1], exhibits a gain of at least 5 dB for the novel turbo HARQ system.

Secondly, the turbo HARQ-B transmission system is investigated. The decrease in throughput of the turbo HARQ-B scheme is not visible whereas a substantial degradation in reliability can be observed when compared to the turbo HARQ scheme. Therefore, the application of the turbo HARQ-B scheme cannot be recommended.
Figure 2: Throughput (dash-dotted line) and BER (solid and dashed lines resp.) vs. $E_s/N_0$ of the turbo HARQ system with $R_c = 1/2$. Transmission over the AWGN channel using BPSK. Interleaver length: 1024. Solid line without marks: Classical turbo decoding acc. to [4]. Solid line marked with “+”: Improved turbo decoding acc. to [9]. Solid line marked with “o”: turbo HARQ system. Dashed line marked with “*”: turbo HARQ–B system.

5 CONCLUSIONS

A novel hybrid automatic repeat request system based on turbo codes, called turbo HARQ system, is proposed. Thereby, properties of the iterative turbo decoding procedure are exploited to request retransmission of a received block. The additional effort for this detection is negligible. An additional outer error-detecting code is not necessary for moderate reliability requirements. It is shown that the turbo HARQ scheme significantly outperforms the classical turbo coding scheme without essential loss in throughput.

REFERENCES


