Iterative Equalization and Decoding for the GSM – System

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Abstract

In iterative equalization and decoding ("turbo-detection") the "turbo–principle" is used for detection of coded data transmitted over a frequency selective channel. Due to the burst and interleaver structure the turbo-detection scheme cannot be adopted to the GSM without modifications. We present some possibilities to adopt turbo detection to TDMA systems with inter-block-interleaving like GSM and show that the turbo principle also works very well if extrinsic information is not available for all bits. Furthermore, we show that turbo-detection is a suitable method to improve the bit error rate not only of protected bits but also of bits transmitted uncoded in a system with unequal error protection, e.g. the class 2 bits in the GSM speech channel.

1 Introduction

The so called "turbo" principle first used in [1] for iterative decoding of parallel concatenated codes can be used in a wide variety of receiver detection and decoder tasks. The basic idea is to use a maximum a posteriori (MAP) detector, which is able to accept not only channel values but also apriori information about the symbols to be detected. This apriori information can be obtained in various ways, e.g. from the feedback of an outer or parallel decoder. As the detector uses the processed output of the outer or parallel decoder as apriori input for the next iteration - similar to a turbo engine - this feedback is called the "turbo–component" of the detection scheme. In [2] the "turbo principle" was first applied to combined equalization and decoding ("turbo–detection", "turbo–equalization").

Iterative equalization and decoding requires modifications only at the receiver. Therefore, it can be implemented in existing mobile communications systems, e.g. the GSM – system.

In TDMA systems like GSM the coded bits of a data block are interleaved and mapped on a number of N bursts. For a better interleaving depth inter–block–interleaving is often applied, that means each burst contains bits from different data blocks. In GSM this is true for the traffic channels. Therefore, when applying turbo detection in the common way all data blocks would have to be transmitted and decoded before processing the first iteration, as in the turbo scheme the equalizer uses apriori information fed back from the decoder. However, most of the traffic channels are subject to delay and memory restrictions. Consequently, the turbo detection scheme has to be modified to be implemented in the GSM system. In this paper the GSM speech channel TCH/FS will serve as an example, but the methods discussed can be used in any system with inter–block–interleaving.

We will present some possibilities to adopt turbo detection to TDMA systems with inter-block-interleaving like GSM and show that the turbo principle also works very well if extrinsic information is not available for all bits. Furthermore, we will show that turbo detection is a suitable method to improve the bit error rate not only of protected bits but also of bits transmitted uncoded in a system with unequal error protection, e.g. the class 2 bits in the GSM speech channel.

2 Principle of Iterative ("Turbo") Equalization and Decoding

A mobile radio channel with intersymbol interference (ISI) including the transmit and receive filters can be regarded as a time–varying convolutional code with complex valued coded symbols, given by the propagation conditions (Figure 1). From this point of view channel

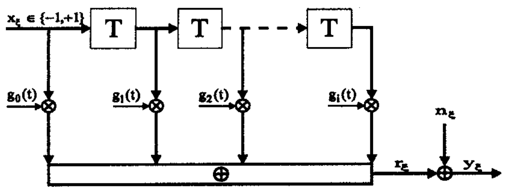

Figure 1: Discrete-time channel model

encoder and ISI–channel form a serially concatenated scheme which can be decoded by an iterative algorithm. We use soft–in/soft–out algorithms for both equalization and decoding that besides the channel values accept further apriori information about the bits to be decoded and deliver soft values of the decoded bits. In iterative detection it is also necessary to obtain soft values about the coded bits at the output of the channel decoder. Therefore, we call the decoder a COD–MAP decoder. It is useful to compute soft values in the form of log–likelihood ratios (L–values):

$$L(x) = \log \frac{P(x=+1)}{P(x=-1)} \tag{1}$$

We will now describe the principle of iterative detection (see Figure 2):

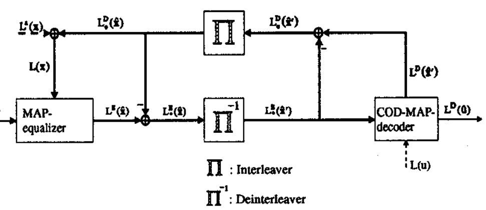

Figure 2: Iterative detection

At the receive filter output we observe the complex valued sequence $\mathbf{y}$. The equalizer delivers L–values $L^E(\hat{x})$ about the coded bits. After deinterleaving, the channel decoder delivers L–values $L^D(\hat{u})$ about the information bits and L–values $L^D(\hat{x}')$ about the coded bits. The L–values at the output of the decoder consist of an extrinsic and an intrinsic part. The extrinsic part is the incremental information about the current bit obtained through the decoding process from all information available for the other bits in a block. It can be calculated by subtracting the L–values at the input of the decoder from the corresponding L–values at the output:

$$L_e^D(\hat{x}'_k) = L^D(\hat{x}'_k) - L_*^E(\hat{x}'_k) \tag{2}$$

The extrinsic information $L_e^D(\hat{x}')$ is interleaved and fed back to the equalizer where it is used as apriori information in a new decoding attempt – constituting the first iteration. Using this apriori information the equalizer is supposed to deliver less erroneous decisions which are again passed to the decoder. Repeating this procedure a few times can improve the bit error rate.
As indicated in Figure 2, an independent apriori information $L(u)$, which e.g. could be known from a source decoder, might be used in the turbo scheme.

3 Iterative Detection for the GSM-System

In the previous section we described iterative equalization and decoding for transmission of data without inter-block-interleaving. However, due to burst and interleaver structure this principle cannot be directly adopted to GSM. The GSM speech channel at full rate TCH/FS may serve as an example to outline the problem. Figure 3 shows the encoding scheme. The RPE–LTP (regular

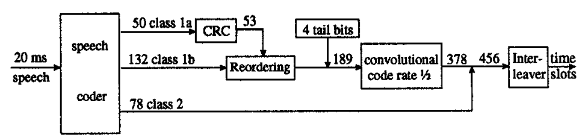

Figure 3: Encoding scheme for the GSM speech channel TCH/FS

pulse excited – long term prediction) speech encoder generates a block of 260 bits per 20 ms speech. According to their importance for the quality of the speech the bits of one block are divided in three classes and encoded by an unequal error protection scheme: The bits of the classes 1a and 1b are protected by a convolutional code whereas the bits of class 2 are transmitted unprotected. Hence, in iterative detection we cannot obtain extrinsic information for the bits of class 2 through a decoding process. On the other hand iterative detection gives the possibility to improve the bit error rate also in the class 2 bits: The mapping by the interleaver should guarantee that during transmission single unprotected class 2 bits are surrounded by coded class 1 bits. This is fairly well achieved by the GSM interleaver. If we obtain a good apriori information for the class 1 bits through the feedback from the decoder, the class 2 bits will also profit due to the constraint length of the channel.
A more severe problem appears due to inter-block-interleaving: Figure 4 shows the principle of mapping

the coded bits on bursts. The 456 bits of one data block

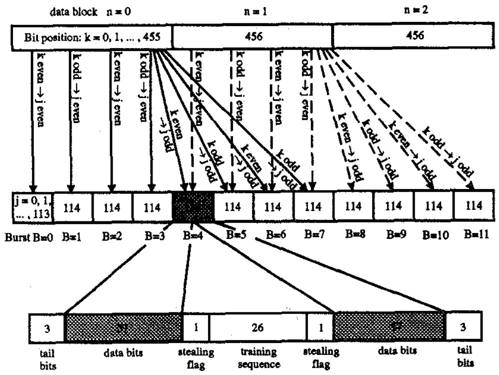

Figure 4: Interleaving for the GSM speech channel TCH/FS.

n to be transmitted for 20 ms speech are mapped on eight successive bursts B. Each burst contains data from two successive data blocks. The even numbered bit positions j of a burst correspond to bits of a data block n+1, the odd numbered bit positions j correspond to bits of the previous data block n. Therefore, in iterative detection we can only obtain apriori information for every second bit (except the class 2 bits) of a burst through the present decoding process of data block n. Let us consider iterative detection for data block n. The first four bursts which contain data from block n also contain data from block n-1 which has been decoded previously. The four last bursts containing data from block n also contain data from block n+1. For decoding of data block n+1 we would have to receive four more bursts containing data from block n+1. However, due to delay restrictions ([3]) we cannot wait until we have received the whole information to decode block n+1 as well.
We now present a number of possibilities – differing in complexity and performance – to solve the problem of inter-block-interleaving in turbo–detection.

3.1 Turbo-Detection without delay restrictions

In a first approach we will disregard delay restrictions. That means we receive and equalize a large number of bursts before we start decoding and the iterative process of turbo–detection. In this way we can obtain apriori information for all coded bits in a burst and evaluate the powerfullness of iterative detection for the GSM system. Later on we will compare the results of modified turbo detection signal processing to this approach. In section 4 we will refer to this approach as scheme A.

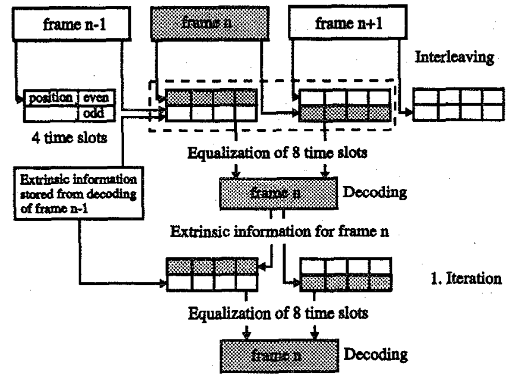

Figure 5: Turbo Detection for frame n (scheme B).

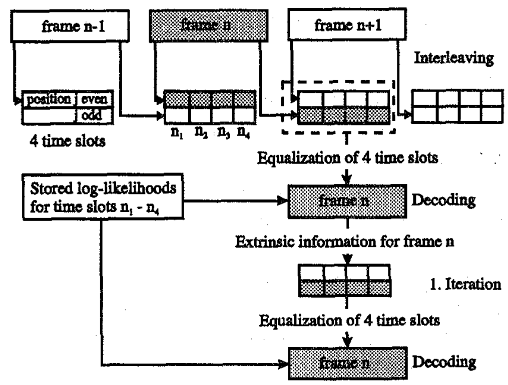

Figure 6: Turbo Detection for frame n (scheme C).

3.2 Data block orientated turbo detection

Figure 5 gives a schematic representation of the solution refered to as scheme B. Each burst is represented by a column with two rows where the first row contains all bits in even numbered bit positions j stemming from data block n. The second row contains all bits in odd numbered bit positions j stemming from the previous data block n-1.
We consider iterative detection for data block n. Detection of all previous data blocks is already finished. In iterative detection of data block n all 8 bursts containing data from block n are equalized in each iteration. The first half of the corresponding bursts contain data from the data blocks n-1 and n, the other bursts contain data from the data blocks n and n+1. Hence, each burst is to be equalized in the processes of iterative detection of two successive data blocks. We obtain no apriori information for the bits stemming from data block n+1. Hence, the apriori information for these bits $L(x_j^{(n+1)}) = 0$ in all iterations. However, as data block n-1 has already been detected, there is apriori information available for the bits stemming from data block n-1 even in the first

equalization step (iteration 0) of turbo detection of data block n. We found that the best solution is to store the extrinsic information obtained in the last performed iteration of iterative detection of data block n-1 and use this extrinsic information as apriori information in all iterations in detection of data block n. An advantage of this scheme is that all extrinsic information which is available at the moment of detection of data block n is used in the iterative process. However, the disadvantage is that each burst has to be equalized in the processes of iterative detection of two successive data blocks.
To reduce computational complexity we can also use an iterative detection scheme where not all bursts containing information of block n are equalized during the iteration process of block n (Figure 6). We will refer to this method as scheme C. During the detection of data block n-1 the first four bursts containing data of block n have been already equalized. The soft equalizer outputs are stored. Therefore, it is not essential to equalize them again during the iterative detection of block n. We only equalize the four new bursts. Then we pass this information together with the stored information from the first four bursts via the interleaver to the decoder. As in scheme B only the apriori information for bits of the current data block n is updated in the iterative process. However, as only the four last bursts containing data from block n are equalized again in the iterative process the extrinsic information obtained for bits in the first four bursts n_1 ... n_4 is never used.
Both schemes B and C can be extended to methods of higher complexity: We can also obtain updated apriori information for the bits from data block n-1 if we also re-decode the data block n-1 during iterative detection of data block n using the improved equalizer outputs.
It is even possible to obtain apriori information for the bits of data block n+1: Using only the equalizer output for the already received, first bursts containing data from block n+1, we can decode the data block n+1 as a punctured code and feed back the extrinsic information to the equalizer. However, the extrinsic information obtained in this way is very small and does not affect the detection result.

4 Simulation Results

Simulations where done for the GSM speech channel at full rate (TCH/FS). We transmitted data over a frequency selective time invariant channel with the impulse response

$$h[n] = 0.227u[n] + 0.46u[n-1] + 0.688u[n-2] + 0.46u[n-3] + 0.227u[n-4].$$

Both equalization and decoding were done using the "symbol by symbol MAP algorithm" [4], [5]. Perfect channel knowledge was assumed.

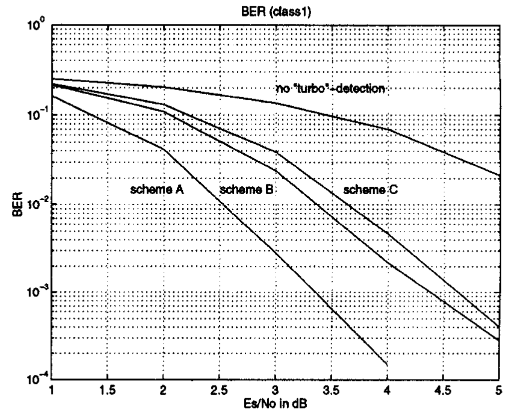

Figure 7: BER in class 1 bits after decoder for detection schemes A, B, C (3 iterations).

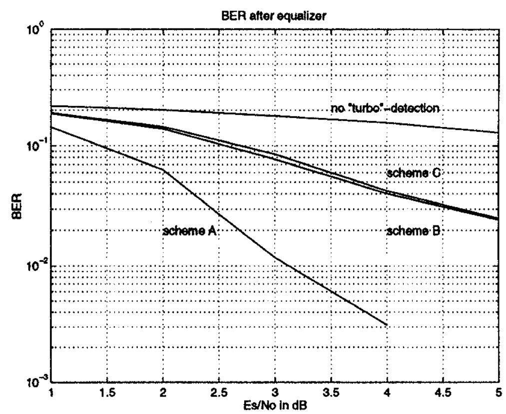

Figure 8: BER after equalizer for detection schemes A, B, C (3 iterations).

Figure 7 shows the bit error rate for the class 1 bits after 3 iterations for the detection schemes A, B, and C. The best results are achieved using scheme A because apriori information can be used for all class 1 bits in all bursts. The degradation of scheme B compared to scheme A is about 1 dB at a BER of 10^{-3}. As expected, there is a further degradation of 0.3 dB when detection scheme C is applied because not all extrinsic information obtained through decoding of a data block is used as apriori information.
Figure 8 shows the BER at the output of the equalizer after 3 iterations for detection schemes A, B, and C. For the schemes B and C the BER is measured for the last four bursts containing data of block n (see Figures 5 and 6). The slightly better BER for detection scheme B compared to scheme C is due to the fact that the extrinsic information fed back from the decoder is better because the soft equalizer outputs for the bursts n_1 ... n_4 (see Figures 6) are updated in each iteration when using scheme B. Figure 9 shows the BER for class 2 bits.

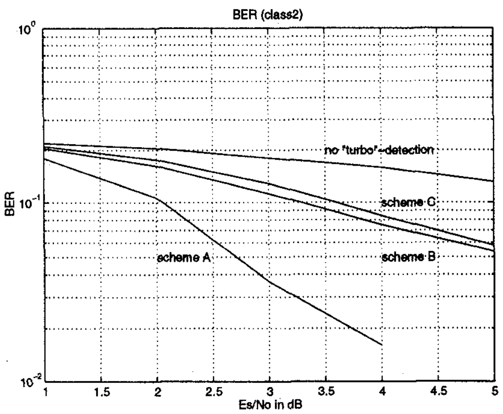

Figure 9: BER in class 2 bits for detection schemes A, B, C (3 iterations).

Despite we do not obtain apriori information for these bits the BER is reduced by iterations due to the constraint length of the channel.
In order to analyze the differences of various detection schemes we used a multipath channel with strong intersymbol interference (ISI) for which turbo-detection works very well. However, for channels with slight ISI turbo-detection is less promising, because due to a small constraint length of the channel the impact of the apriori information used by the equalizer becomes very small. Even for the COST-profiles specified for GSM, e.g. typical urban, only a small gain in the average BER can be achieved by turbo-detection. However, if other evaluation criteria are applied, e.g. a satisfied user criterion measuring the BER in certain periods, turbo-detection is more promising.

5 Conclusions

Iterative equalization and decoding ("turbo detection") is a suitable method to reduce the effects of strong intersymbol interference. As turbo detection only affects the receiver, it can be implemented in existing mobile communications systems. However, due to delay and memory restrictions the turbo detection scheme has to be modified when inter-block-interleaving is applied. We have proposed possibilities to adopt turbo detection to systems with inter-block-interleaving. For the GSM speech channel TCH/FS we have shown that the turbo principle also works well when extrinsic information is not available for all bits and that also bits transmitted uncoded in a system with unequal error protection, e.g. the class 2 bits, can gain from the iterative process.

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