Dummy Bit Rate Matching for UMTS LTE

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Abstract

In UMTS LTE rate matching is performed by means of puncturing and repetition in order to adjust the code rate with respect to the supported transmission rates. In this proposal we describe an alternative approach for the repetition case where known bits (dummy bits) are inserted into the bit sequence prior to channel coding. These bits provide perfect *a priori* information which can be exploited by the iterative soft input soft output (SISO) turbo decoder for the decoding of the information bits. Extensive simulations have verified that superior decoding quality in terms of bit error rate and faster convergence can be achieved by the novel dummy bit rate matching compared to the standardized UMTS LTE rate matching.

1 Introduction

The latest release of the UMTS LTE standard [1, 2] features a flexible physical layer employing turbo channel coding, rate matching by adaptive puncturing or repetition of encoded bits, *hybrid automatic repeat-request* (HARQ), a choice of complex signal constellations (quadrature phase shift keying (QPSK), 16QAM, and 64QAM, all with Gray mapping), and cyclic prefix *Orthogonal Frequency Division Multiplexing* (OFDM) with a bandwidth dependent number of subcarriers for downlink modulation. The choice of the modulation and coding scheme for each individual user, i.e., the code rate and complex signal constellation, is left to the scheduler based on the instantaneous channel conditions and the current load of the radio cell.

In this contribution we show that significant gains in terms of residual bit error rate (BER) and convergence behavior can be achieved by a simple modification of the rate matching scheme. Instead of employing repetition coding for flexibly decreasing the code rate, we recommend to insert known bits (dummy bits) into the information sequence before convolutional turbo encoding. These bits provide perfect *a priori* information which can be exploited by the SISO decoder for the decoding of the information bits. This method is related to the approach introduced by Xu and Romme [8] for non-iterative convolutional coding schemes which revealed slight decoding improvements in terms of residual BER only for special convolutional codes and special code rates. We presented a first successful application to iterative source-channel decoding [3, 5] has been presented in [4]. In what follows, we have adapted this method to the UMTS LTE turbo coding scheme by developing an optimal systematic insertion scheme resulting in a more effective rate matching, particularly, in the case of turbo decoding.

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This contribution is organized as follows: The system model for the considered UMTS LTE physical layer and its parameters are sketched in Sec. 2. Sec. 3 introduces the novel dummy bit rate matching based on an optimal insertion scheme. Simulation results demonstrating the BER performance and the convergence behavior are given in Sec. 4.

2 UMTS LTE Transmission System

The model of the UMTS LTE transmission system is depicted in Fig. 1. According to the LTE standard, a block of information bits $\underline{x}$ of a given size M is encoded by a systematic rate-$\frac{1}{3}$ turbo coder consisting of two parallel concatenated convolutional codes (PCCC) with octal generator polynomial $G = \{1, 15/13\}_8$ each generating one parity bit per information bit. The encoded bits are then separated into three streams: The first contains the systematic, i.e., the uncoded information bits $\underline{x}$, while the second and third contain the parity bits of the two constituent encoders $\underline{p}_{\mathrm{I}}$ and $\underline{p}_{\mathrm{II}}$, respectively. For an efficient and easy to implement rate matching the three streams are individually interleaved and written to a ring buffer. For details of the rate matching algorithm the reader is referred to [2].

For a given number M of information bits a block of N encoded bits is selected for transmission, resulting in an effective code rate $r = \frac{M}{N}$. The size N of the block of encoded bits is determined by the scheduler according to the user's instantaneous channel quality, the user's requested throughput, maximum delay, target BER and the current load of the radio cell. Thereby the scheduler implicitly influences the code rate r of the user. A block size $N < 3 \cdot M$ results in a code rate $r > \frac{1}{3}$, whereas if N is sufficiently large, the code rate r can take values $r < \frac{1}{3}$ by repetition of systematic and parity bits.

The bits selected for transmission are grouped to vectors of I bits with $I \in \{2, 4, 6\}$ which then are assigned to complex modulation symbols $Y \in \mathcal{Y}_I$ of signal constellation symbols $\mathcal{Y}_I$, i.e., QPSK, 16QAM, or 64QAM. The complex modulation symbols $\underline{Y}$ are then OFDM modulated and a cyclic prefix (CP) is added to form the transmit signal $\underline{y}$ with averaged unit power. OFDM modulation is realized using an Inverse Fast Fourier Transform (IFFT) of size 2048 (20 MHz system bandwidth). The channel is disturbed by complex additive Rayleigh distributed noise samples $\underline{n}$ with zero mean and normalized noise power N_0.

On the receiving side the CP is removed and OFDM demodulation is performed employing the Fast Fourier Transform (FFT). The demodulated complex symbols are fed to a soft demapper (SDM) which delivers reliability information in form of *extrinsic log-likelihood ratios* (LLR) $\underline{L}^{[\mathrm{ext}]}(\underline{x})$, $\underline{L}^{[\mathrm{ext}]}(\underline{p}_{\mathrm{I}})$, and $\underline{L}^{[\mathrm{ext}]}(\underline{p}_{\mathrm{II}})$ on the systematic information bits $\underline{x}$ and the parity bits of the two constituent encoders $\underline{p}_{\mathrm{I}}$, $\underline{p}_{\mathrm{II}}$, respectively. The LLRs are then passed on to a parallel turbo decoding structure consisting of two soft

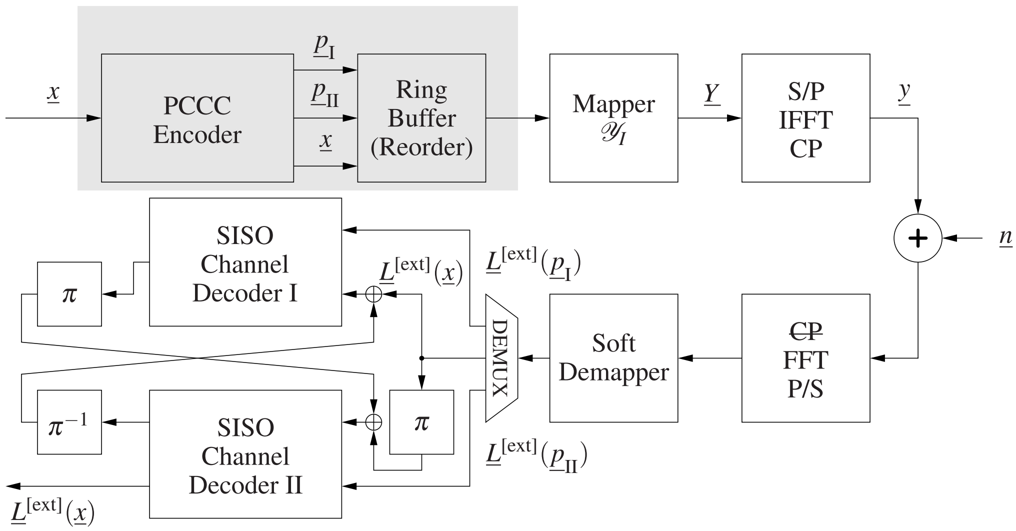


Figure 1: UMTS LTE transmission system model.

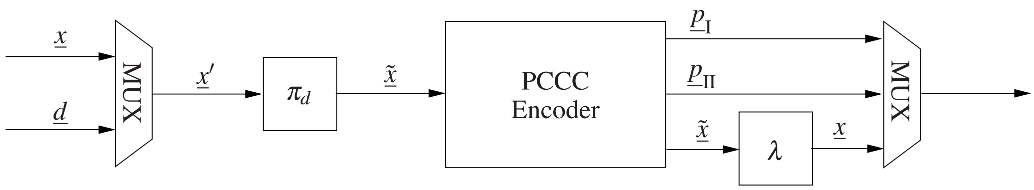


Figure 2: Dummy bit rate matching (DBRM) for UMTS LTE.

input soft output (SISO) channel decoders (CD) using the LogMAP algorithm [6] for soft channel decoding. For the initial decoding step after soft demapping the LLRs are fed into CD I without using any a priori information. The obtained extrinsic information is properly interleaved and fed into CD II as a priori information. From this a priori information together with the LLRs from the soft demapper CD II generates extrinsic information for the next decoding iteration in CD I. After a fixed number of decoding iterations the sequence of information bits are estimated from the resulting LLRs.

3 Dummy Bit Rate Matching

The dummy bit rate matching (DBRM) is an alternative to the UMTS-LTE rate matching employing repetition which enables the generation of lower code rates from a mother code with fixed code rate. It modifies the components highlighted by the gray box in Fig. 1 according to the structure depicted in Fig. 2. Data bits $\underline{x}$ and fixed dummy bits $\underline{d}$ are multiplexed forming the vector $\underline{x}' = [\underline{x}\ \underline{d}]$. Without loss of generality zeros are chosen as dummy bits. Then, a deterministic interleaver π_d is employed to rearrange the dummy bits within the vector $\underline{x}'$ according to a predefined pattern which is specified at the end of this section. The resulting vector $\underline{\tilde{x}}$ is then fed to the systematic rate-1/3 PCCC encoder which again generates two parity bits for each input bit. Since *systematic dummy bits* do not deliver additional information to the PCCC decoder at the receiver side, these bits can be eliminated by a puncturer λ saving energy and bandwidth consumption. Consequently, only the information bits $\underline{x}$ and the parity bits $\underline{p}_{\mathrm{I}}$, $\underline{p}_{\mathrm{II}}$ containing information about the information bits as well as the dummy bits that are transmitted over the channel. Hence, the code rate after dummy bit rate matching amounts to

$$r_{\mathrm{DBRM}} = \frac{M}{(M+L)\cdot r_{\mathrm{PCCC}} - L}, \tag{1}$$

where M denotes the number of information bits, L the number of dummy bits and $r_{\mathrm{PCCC}} = 1/3$ the rate of the employed convolutional turbo code.

At the receiver side, the dummy bits and their positions are known and can be exploited as perfect reliability information $\underline{L}^{[\mathrm{ext}]}(\underline{d}) \to \infty$ for the turbo decoding of the information bits. The reason is that the structure of the employed convolutional code generates strong dependencies between adjacent input bits of the convolutional encoder. Consequently, the knowledge of the dummy bits helps to improve the *extrinsic* reliabilities of the information bits $\underline{L}^{[\mathrm{ext}]}(\underline{x})$ and provides better protection against channel impairments.

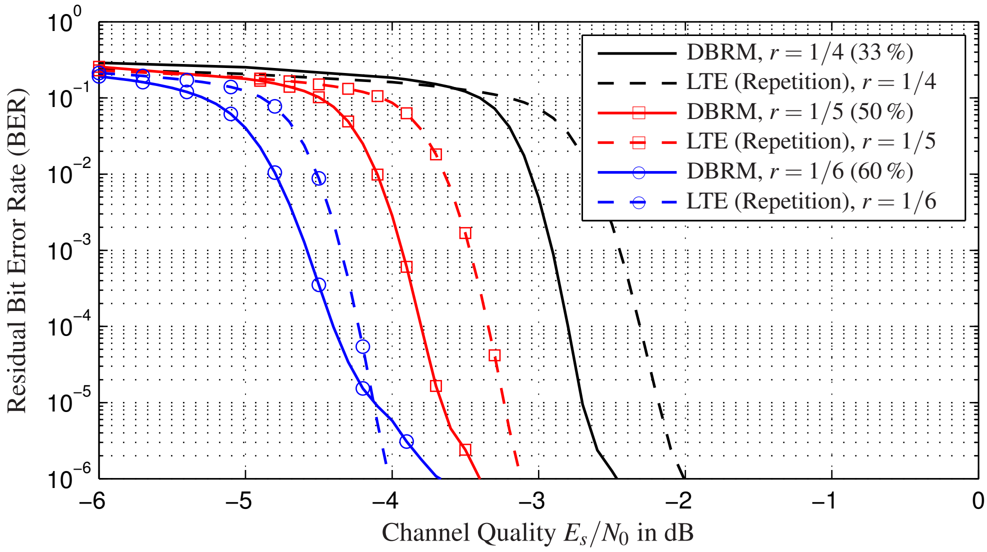
The above description implicates that the interleaver design is a crucial issue in such a system and has a considerable influence on the system performance. The deterministic interleaver developed for the considered system distributes the fraction of dummy bits L equidistantly (as far as possible) over the complete data block of length $N = L+M$ following the below given design rules:

$$\alpha = \frac{L}{M} + 1, \tag{2}$$

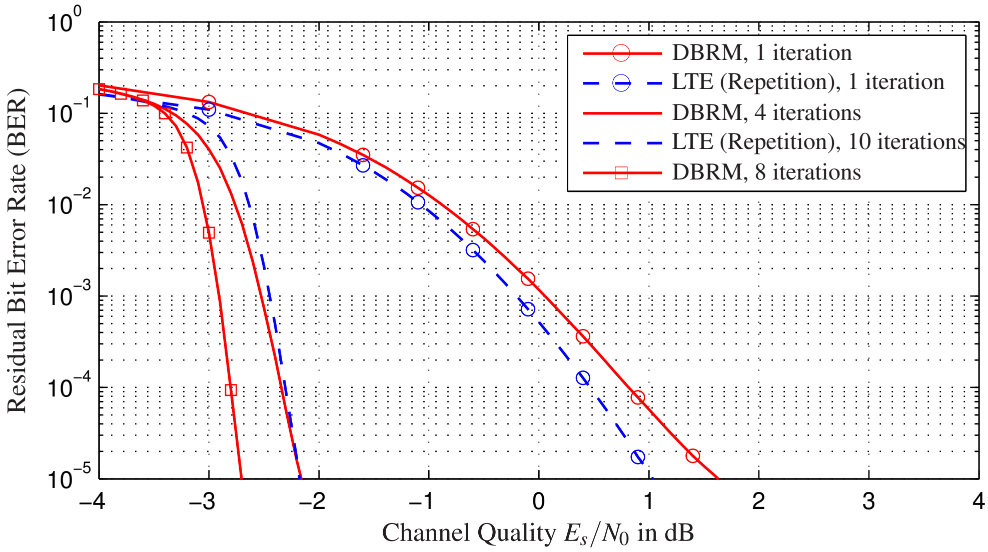
$$\underline{\tilde{x}}\,(i_x(j)) = \underline{x}(j) \tag{3}$$

$$i_x(j) = \mathrm{round}\,(j\cdot\alpha)\ , \quad 0 \le j < M. \tag{4}$$

The factor α denotes the step size of the information bits within the data block $\underline{\tilde{x}}$ and may be non-integer if M is not a factor of L. The integer indexes $i_x(j)$ of the information bit



(a) Comparison in terms of residual bit error rate for different code rates and 10 turbo iterations.



(b) Comparison in terms of convergence behavior for target code rate $r = 1/4$ and a variable number of turbo iterations.

Figure 3: Comparison of dummy bit rate matching (DBRM) and rate matching by repetition for UMTS LTE in terms of their residual bit error rates (BERs) and their convergence behavior.

positions can then be computed by means of the fractional step size α and the function round$(\cdot)$ which rounds its argument to the nearest integer value. This algorithm ensures the desired equidistant spacing of dummy bits within the interleaved data block $\underline{\tilde{x}}$ for any fraction of dummy bits. This is illustrated by the following example: Let us consider a scenario where $L = 4$ dummy bits $\underline{d} = [d_1 \ldots d_4]$ are inserted into a block of $M = 6$ data bits $\underline{x} = [x_1 \ldots x_6]$. Following the design rules of the proposed interleaver, the output block is given by

$$\underline{\tilde{x}} = [x_1\, x_2\, d_1\, x_3\, d_2\, x_4\, x_5\, d_3\, x_6\, d_4]. \tag{5}$$

The above described deterministic interleaver realization has proven to be most suitable for the proposed dummy bit rate matching since the dummy bit information is equally distributed and the perfect information $\underline{L}^{[\mathrm{ext}]}(\underline{d}) \to \infty$ can be exploited best possible at the receiver.

4 Evaluation

In order to highlight the benefit of the dummy bit rate matching compared to the UMTS LTE rate matching based on repetition, we have simulated a transmission over an AWGN channel for different target code rates $r \in \{1/4, 1/5, 1/6\}$, $r < 1/3$ at first. A fixed data block size of 6144 bits which corresponds to the maximum data block size in LTE systems [2] is chosen and 10 turbo iterations are carried out. Without loss of generality, QPSK has been employed as modulation scheme and no HARQ has been considered. We have compared both systems in terms of their residual bit error rate (BER) in Fig 3a. The dummy bit fraction $L/(M+L)$ associated with each target code rate is given in brackets. Assuming a target BER of 10^{-4}, a gain of approximately 0.5 dB can be achieved for code rates $1/5 < r < 1/3$. Below these rates a reduced gain is observed. For the example of $r = 1/6$ a gain of 0.2 dB is obtained and an intersection at a residual BER of 10^{-5}

is observed. The worse behavior for lower code rates than $r = 1/5$ originates from the high fraction of dummy bits. If more than 50 % dummy bits are inserted into the data block, there will exist patterns where dummy bits are adjoining which leads to no information gain and, thus, to no considerable decoding performance gain.

In a further evaluation, we have compared both systems in terms of their convergence behavior in Fig. 3b. In the non-iterative case (1 iteration) there is no improvement in terms of residual BER achieved by the dummy bit rate matching. Nevertheless, in the iterative case a much higher convergence speed can be observed. Only 4 iterations are sufficient to obtain equal performance compared to the conventionally employed repetition coding carrying out 10 iterations. This leads to a considerable complexity reduction. However, for a fair comparison we have to take into account that the complexity of 1 iteration is increased in the case of dummy bit rate matching due to the insertion of bits prior to channel encoding. According to [4] the complexity of 1 iteration in the considered system employing dummy bit rate matching is approximately 1.25 times as high as the complexity introduced by the repetition coding. This leads to an overall complexity reduction of

$$\Delta\mathscr{C} = 1 - \frac{\mathscr{C}_{\mathrm{DBRM}}}{\mathscr{C}_{\mathrm{Rep}}} = 1 - \frac{4 \cdot 1.25}{10} = 50\,\% \tag{6}$$

assuming 4 iterations for the dummy bit rate matching and 10 iterations for the repetition coding. Alternatively, a gain of 0.4 dB in terms of residual BER can be achieved for equal complexity by the dummy bit rate matching (8 iterations) compared to the conventional rate matching employing repetition (10 iterations).

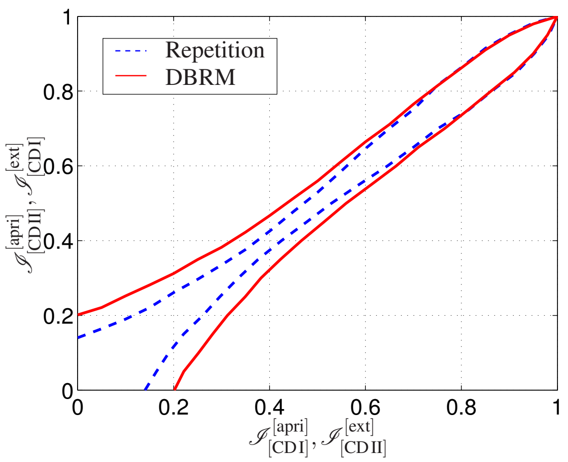


Figure 4: EXIT characteristics of the SISO component decoders (rate matching with $r = 1/4$, $E_s/N_0 = -2.8$ dB).

Additionally, these simulation results are confirmed by an analysis of the Extrinsic Information Transfer (EXIT) chart [7]. The EXIT chart describes the flow of extrinsic information $\mathscr{I}^{[\mathrm{ext}]}$ between two SISO decoding components CDI and CDII given a certain a priori information $\mathscr{I}^{[\mathrm{apri}]}$. The EXIT chart is therefore perfectly suited to describe the convergence behavior of an iterative turbo decoding process where two SISO channel decoders exchange extrinsic information. The EXIT chart in Figure 4 has been simulated exemplarily for a code rate of $r = 1/4$ with a channel quality of $E_s/N_0 = -2.8$ dB. It is clearly visible that the use of dummy bit rate matching causes a reshaping of the EXIT chart by widening the characteristics of the two component decoders, especially for smaller a priori information. As shown before, the widening of the decoding tunnel between the two component decoder characteristics results in a much faster convergence with fewer Turbo iterations.

5 Conclusion

In this contribution, we have proposed an alternative method to perform rate matching in the UMTS LTE transmission system. A distinct number of known bits (dummy bits) are inserted into the information sequence at optimized positions before convolutional turbo encoding in order to match the desired target code rate. This method shows superior decoding performance in terms of residual bit error rate for a wide range of commonly applied target code rates compared to the standardized UMTS LTE rate matching employing repetition coding. Furthermore, an EXIT chart analysis has proven that the convergence can be significantly sped up by the novel dummy bit rate matching.

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