LTE Rate Matching Performance with Code Block Balancing

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***Abstract*—In this paper, we compare the performance of the LTE rate matcher for different code rates when segmentation occurs. We present that, for certain cases of segmentation where the different segments are of dissimilar size, the rate applied to each segment may be different and thus degraded overall performance may occur. We show how a simple method which balances the code rate on a per-segment basis can improve the overall block error ratio performance. The whole simulation environment together with the results of this paper are made available for download at our homepage.**

I. Introduction

Current cellular systems, such as HSDPA, LTE and WiMAX employ Adaptive Modulation and Coding (AMC) as one of the means to adapt the data rate to the channel conditions. After channel estimation [2, 3], User Equipment (UE) feeds back channel quality information, which the transmitter uses to perform AMC. In all of these systems, AMC is implemented as a combination of a fixed $1/3$ turbo encoder and a rate matching process [4].

By means of rate matching, any arbitrary code rate can be achieved from a fixed-rate mother code. Any code rate (r) can be obtained from the initial $1/3$ code via a process of bit puncturing (for $r > 1/3$) or repetition ($r < 1/3$). In addition, as all coded bits are obtained from the originally $1/3$-encoded codeword, rate matching also allows for Hybrid Automatic Repeat Request (HARQ) combining to be performed [5–7].

One effect attached to the implementation of rate matching is segmentation. Due to implementation issues, the turbo encoder/decoder hardware is able to process/interleave blocks of up to a certain size. If blocks bigger than the maximum interleaver size are to be encoded, the block is segmented and its parts individually coded. Then, in order to have a successful decoding, all individual segments must be correctly received.

This paper investigates the performance of the LTE rate matcher in situations where segmentation occurs, and focuses on high order Modulation and Coding Schemes (MCSs). The 3GPP working group considered several proposals during standardization. however, the currently used solution was chosen for simplicity [8]. We show that, in case of dissimilar block segment sizes, performing the rate matching on a per-segment basis can improve performance.

The remainder of this paper is organized as follows. In Section II we describe the LTE rate matching process. Section III shows the performance degradation that occurs when segmentation is applied and how this degradation can be mitigated when performing the rate matching on a per-segment basis. We conclude the paper in Section IV.

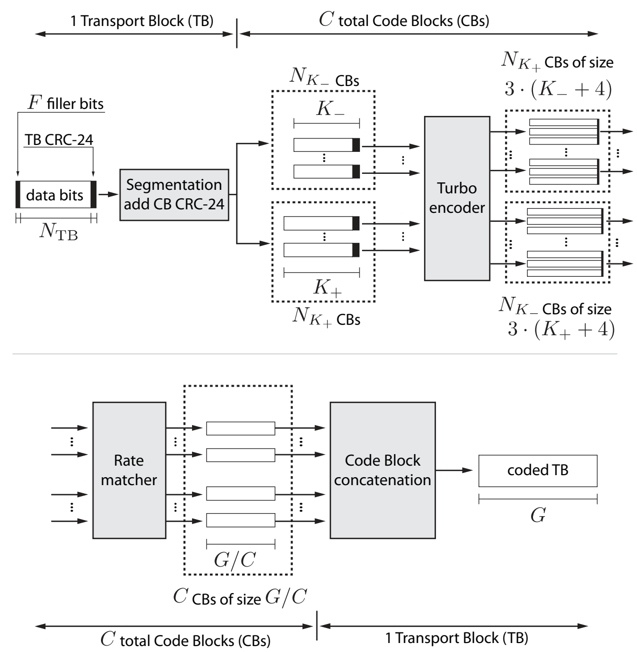

Fig. 1. Transport block segmentation, turbo encoding, rate matching, and code block concatenation procedures defined for LTE [9].

II. Rate matching in LTE

The rate-matching process defined for LTE divides the channel coding procedures in the steps seen in Figure 1 [9]. It employs the rate $1/3$ WCDMA turbo code [10] with a new interleaver based on a Quadratic Permutation Polynomial (QPP) [11, 12].

The data bits, which comprise a transmission unit, i.e. Transport Block (TB), consist of N_{TB} bits. After the channel coding, G bits are output, such as the Effective Code Rate (ECR) of the TB ($\mathrm{ECR_{TB}}$) is N_{TB}/G.

The standard defines 188 possible interleaver sizes the turbo encoder may use, ranging from 40 to 6144 bits. In order to encode the N_{TB} data bits, the TB plus 24 CRC bits are divided

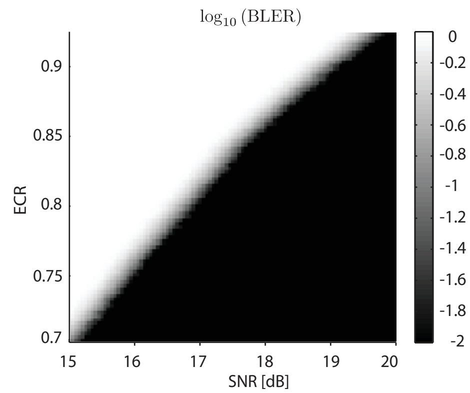

Fig. 2. BLER performance in logarithmic scale over SNR and effective code rates between 0.7 and 0.92 using 64-QAM modulation. ECR $= N_{\mathrm{TB}}/G$. Plotted BLER clipped to 10^{-2}. 6,120 N_{TB} bits (maximum interleaver size minus CRC-24).

into C Code Blocks (CBs) (segments) which are independently encoded/decoded. In order for the TB to be decoded correctly, all of its segments must be received correctly in the same transmission (codeblock-wise retransmission is not supported). The segmentation process divides the TB into N_{K_-} blocks of size K_- and N_{K_+} blocks of size K_+, where K_+ and K_- are valid interleaver sizes such that $K_- \leq K_+$. F filler bits are added to the beginning of the N_{TB} data bits so that the TB can be integerly divided into the C CBs (i.e. the first CB). Thus, for the case when segmentation is applied:

$$N_{\mathrm{TB}} + F + (C+1)\cdot 24 = N_{K_+}\cdot K_+ + N_{K_-}\cdot K_- \quad (1)$$

$$N_{K_+} + N_{K_-} = C \quad (2)$$

Included in K_+ and K_- is a 24-bit CRC, which is not included when no segmentation is necessary. Nevertheless, in this paper we will focus on the case where segmentation is present, thus assuming the presence of the 24 CRC bits per CB.

After the turbo encoding process, which includes the 4 termination bits (T) of the Recursive Systematic Code (RSC), the output consists of $3\cdot\left[\left(N_{K_+}\cdot K_+ + T\right) + \left(N_{K_-}\cdot K_- + T\right)\right]$ bits.

Subsequently, the resulting coded bits are rate-matched to G bits so that $\frac{N_{\mathrm{TB}}}{G} = \mathrm{ECR}_{\mathrm{TB}}$, thus obtaining C CBs of size G/C. The actual ECRs applied a CB (CB_i) of size K_i bits is then (excluding the F filler bits):

$$\mathrm{ECR}_{\mathrm{CB}_i} = \frac{K_i - (1+1/C)\cdot 24}{N_{\mathrm{TB}}/\left(C\cdot \mathrm{ECR}_{\mathrm{TB}}\right)}, \quad (3)$$

Figure 2 shows the Block Error Ratio (BLER) performance of the LTE channel coding for different ECRs when no segmentation takes place.

For high code rates, it is thus expected that the actual different CB ECRs applied can lead to dissimilar BLER performance for different segments of the TB.

TABLE I
SIMULATION PARAMETERS

CQI	ECR	C	K_+	K_-	N_{TB}
14	0.85	3	4160	4096	12256
		1	4072		4072
15	0.92	3	5248	5184	15552
		1	5160		5160

Figure 2 shows the AWGN BLER performance over SNR and ECR for a 64-QAM transmission at high code rates. 64-QAM is the preferred modulation for high throughput, hence has been used to depict the ECR effect in BLER performance, as opposed to the more usual QPSK. The simulation was performed using the maximum interleaver size of 6144 bits and no segmentation.

It can be seen from the plot that a small difference between the set ECR and the one actually used can lead to big differences in BLER performance. Since the overall TB BLER performance is expressed as

$$\mathrm{BLER}_{\mathrm{TB}} = 1 - \prod_{i=1}^{C}\left(1 - \mathrm{BLER}_{\mathrm{CB}_i}\right), \quad (4)$$

the overall performance is dominated by the worst-performing CB, while it is optimal when all CBs perform equally. i.e. $\mathrm{BLER}_{\mathrm{TB}} = 1 - \left(1 - \mathrm{BLER}_{\mathrm{CB}}\right)^C$.

III. Code block balancing and simulation results

The performance degradation for certain TB sizes has been assessed via LTE link level simulations [13] on an AWGN channel. Since performance degradation due to TB segmentation is only expected for high ECRs, only such cases have been simulated. The LTE standard defines 15 MCSs, which are used for Channel Quality Indicator (CQI) reporting [14]. These range from CQI 1, with an ECR of $1/13$ and 4-QAM modulation, to CQI 15, which uses a code rate of 0.92 and 64-QAM. From these, the upper two have been used in this paper. Simulations were performed for a case where segmentation occurs with $K_+ \neq K_-$ and for a case with no segmentation. For the unsegmented case, N_{TB} has been chosen to be as close as possible to the CB size in the segmented case. The used simulation parameters can be found in Table I.

In the unbalanced simulation, rate matching is performed according to the LTE standard (each CB i is set to G/C bits), while in the balanced one, CB balancing is performed by simply setting the target number of bits for each CB to

$$G_{\mathrm{CB}_i} = G\,\frac{K_i}{\sum_{i=1}^{C} K_i}, \quad (5)$$

where G_{CB_i} is the number of resulting bits after the rate-matching of the i-th CB, and K_i the size of the i-th CB (either K_+ or K_-).

A perfect balancing may be nevertheless not possible due to having to assure that each CB is comprised of an integer number of transmit symbols (in the 64-QAM case, modulo 6).

Simulation results for both the balanced and unbalanced rate matching for CQIs 14 and 15 are shown in Figures 3 and 4, respectively.

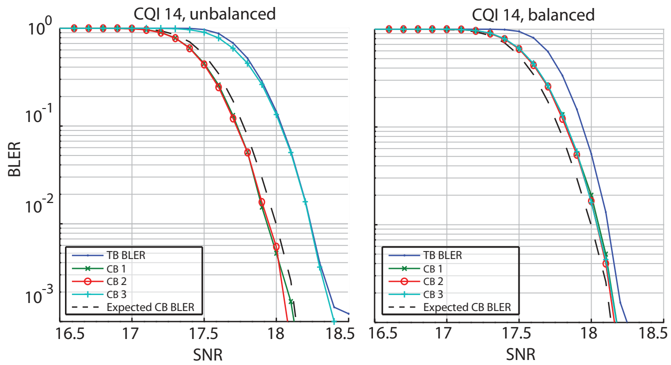

Fig. 3. Code block and transport block BLER performance: CQI 14 (64-QAM, 0.85 ECR). Left: standard rate matching. Right: codeblock-wise balanced rate matching.

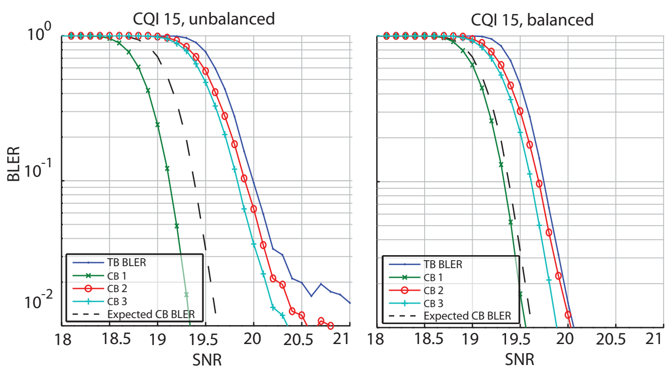

Fig. 4. Code block and transport block BLER performance: CQI 15 (64-QAM, 0.92 ECR). Left: standard rate matching. Right: codeblock-wise balanced rate matching.

Each of them employs the parameters shown in Table I, and show results for the segmented ($C = 3$) and unsegmented CB and TB BLER, as well as the expected TB BLER.

The different ECRs applied to each segment result in an overall degraded performance of the decoding of the TB, as the performance is dominated by the worst-performing CB. By balancing the rate matching, the difference in performance between each CB ($\mathrm{BLER}_{\mathrm{CB}_i}$) is greatly reduced. As a result, and since overall BLER performance is dominated by the worst-performing CB/s, overall TB performance is also improved.

IV. Conclusions

In this paper, we assess the performance of the LTE rate matcher in cases where segmentation occurs. When the segments are of dissimilar size, block error ratio performance degradation can occur due to the performance of the whole decoding being dominated by the worst-performing block. We show that by by applying a per-segment rate matching, codeblock performance can be balanced and as a result overall performance improved.

All data, tools and scripts are available online in order to allow other researchers to reproduce our results [1].

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