IMPROVING UMTS LTE PERFORMANCE BY UEP IN HIGH ORDER MODULATION

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Abstract In this contribution we investigate the performance of the UMTS *Long Term Evolution* (LTE) physical layer using turbo coding and 64QAM with Gray mapping. We show how the mapping of systematic and parity bits to the six different bit positions defining one complex 64QAM symbol influences the convergence of the turbo decoder and thereby the bit error rate (BER) performance as well as number of necessary decoding iterations. Exploiting the *unequal error protection* (UEP) property of Gray mapped 64QAM results in an SNR performance gain of approximately 2 dB for the non-iterative system and in addition leads to a significant reduction of the necessary decoding iterations when iterative decoding is performed.

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 (BPSK, QPSK, 16QAM, and 64QAM all with Gray mapping), and cyclic prefix *Orthogonal Frequency Division Multiplexing* (OFDM) with a bandwidth dependent number of subcarriers. 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 how significant gains in terms of necessary turbo decoding iterations can be achieved by a simple reordering of

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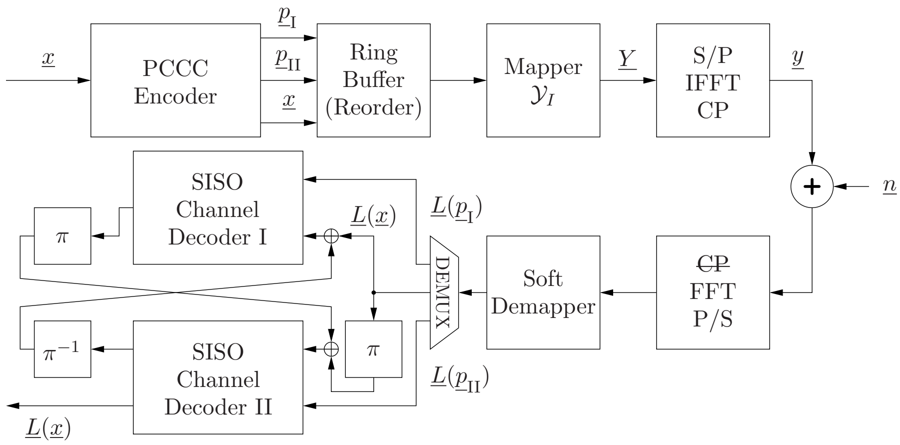


Figure 1. Transmission system model.

the encoded bits of the LTE turbo coder taking into account the unequal error protection (UEP) property of Gray mapped 64QAM. Therefore, following this introduction the system model for the considered UMTS LTE physical layer and its parameters are sketched in Sec. 2. Section 3 analyzes the employed UEP property and introduce the proposed reordering. Simulation results demonstrating the convergence behavior and the bit error rate performance are given in Sec. 4.

2. System Model

The model of the considered transmission system is depicted in Fig. 1. According to the LTE standard, a block of data bits $\underline{x}$ of a given size 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 data bit. The encoded bits are then separated into three streams: The first contains the systematic, i.e., the uncoded data bits $\underline{x}$, whereas 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 [3]. For the sake of simplicity the subinterleavers of these streams are omitted as they do not influence the results for the selected channel model.

For a given number n of data bits a block of m encoded bits is selected for transmission resulting in an effective code rate $r = \frac{n}{m}$. The user's requested throughput and the size m of the block of encoded bits is determined by the scheduler according to the user's instantaneous channel quality, 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 $m < 3 \cdot n$ results in a code rate $r > \frac{1}{3}$, whereas if m is sufficiently large, the code rate r can take values $r < \frac{1}{3}$ by repetition of systematic and parity bits.

Furthermore, the LTE HARQ scheme allows for up to four transmissions of different combinations of systematic and parity bits, the so-called *redundancy versions*. For the initial transmission, first, the systematic bits are selected and the remaining space of the code block of size m is then filled up with parity bits. Each following retransmission which may be requested by the receiver starts at a different position within the ring buffer, i.e., each redundancy version consists of a different combination of systematic and parity bits. Obviously, each retransmission of a code block implicitly results in a decrease of the effective code rate and directly leads to losses in throughput and latency. It is therefore highly desirable to achieve a certain target BER already after decoding of the initial transmission of a code block. For details of the rate matching algorithm the reader is referred to [2]. In the following investigations we exemplarily choose $r = \frac{1}{3}$ coding, i.e., the transmission of all systematic and parity bits obtained from the turbo coder for a fixed data block size of 6144 bits. This corresponds to the maximum data block size in LTE systems [2]. Furthermore, only the first redundancy version, i.e., the initial transmission is considered.

The bits selected for transmission are grouped to vectors of I bits with $I \in \{1, 2, 4, 6\}$ which then are assigned to complex modulation symbols $Y \in \mathcal{Y}_I$ out of a of signal constellation symbols $\mathcal{Y}_I$, i.e. BPSK, QPSK, 16QAM, or 64QAM. In this work we consider $I = 6$ bits per modulation symbol and $\mathcal{Y}_6$ corresponding to a Gray mapped 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). To prove the potential of our approach we start with a complex additive white Gaussian noise (CAWGN) channel model: The signal is disturbed by noise samples $\underline{n}$ with zero mean and one-sided noise power $N_0/2$.

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 *log-likelihood ratios* (LLR) $\underline{L}(\underline{x})$, $\underline{L}(\underline{p}_{\mathrm{I}})$, and $\underline{L}(\underline{p}_{\mathrm{II}})$ on the systematic (data) 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 input soft output (SISO) channel decoders (CD) using the MaxLogMAP algorithm [4] 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 etc. After a fixed number of decoding iterations the sequence of data bits are estimated from the resulting LLRs.

3. UEP and Proposed Bit Reordering

Considering a high order modulation scheme like 64QAM with Gray mapping as given in [1] it can be observed that each bit position or bit level in the 6 bit symbol exhibits a different BER and therefore a different level of protection in an AWGN environment. This is illustrated by Fig. 2 where the mutual information $\mathcal{I}\hat{=}\mathcal{I}(X;L)$ between transmitted bit X and received LLR L as obtained from the SDM for each bit position of the 64QAM mapping is plotted versus the channel quality given as signal-to-noise ratio (SNR) E_S/N_0. The mutual information

$$\mathcal{I}(X;L) = \frac{1}{2}\cdot\sum_{x=0,1}\int_{-\infty}^{+\infty} p_L(\xi|X=x)\cdot\mathrm{ld}\frac{2\cdot p_L(\xi|X=x)}{p_L(\xi|X=0)+p_L(\xi|X=1)}\mathrm{d}\xi$$

$$\text{with} \qquad 0 \leq \mathcal{I} \leq 1$$

as defined in [5] uses distributions p_L determined in simulations and serves here as a measure of the protection of each bit level.

It is observed that for the six bits (Bit $0,\ldots,5$) of each Gray mapped 64QAM symbol there exist four different levels of protection, i.e., two groups consisting of two bits (first group: Bits 2 and 3, second group: Bits 4 and 5, cf. Fig. 2) exhibit the same error protection properties while the best protection against bit errors at low channel qualities ($E_S/N_0 < 7\,\mathrm{dB}$) is provided by Bits 0 and 1. This behavior can be interpreted as an unequal error protection property inherent in 64QAM with Gray mapping.

There are various ways of making use of UEP in communication systems. In this contribution we exploit it for unequally protecting systematic and parity bits. The employment of UEP for systematic and parity bits of a turbo coded system has been shown, e.g., in [6] where a faster convergence of a joint turbo decoding and channel estimation process is observed if systematic bits get stronger protection against errors than parity bits. This directly leads to gains in the BER performance in case

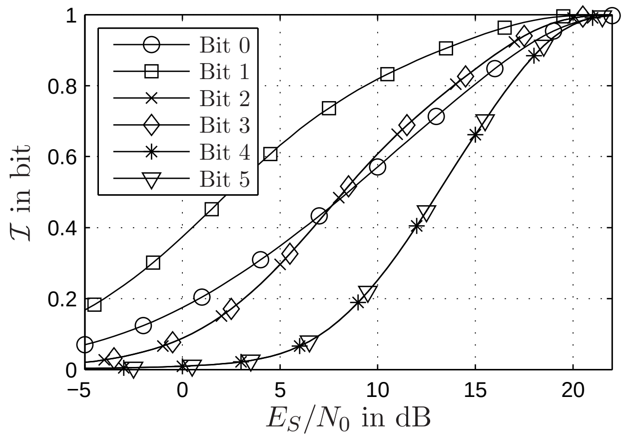


Figure 2. Mutual information $\mathcal{I}$ between transmitted bits and received LLRs versus channel quality for the different bit levels of 64QAM with Gray mapping.

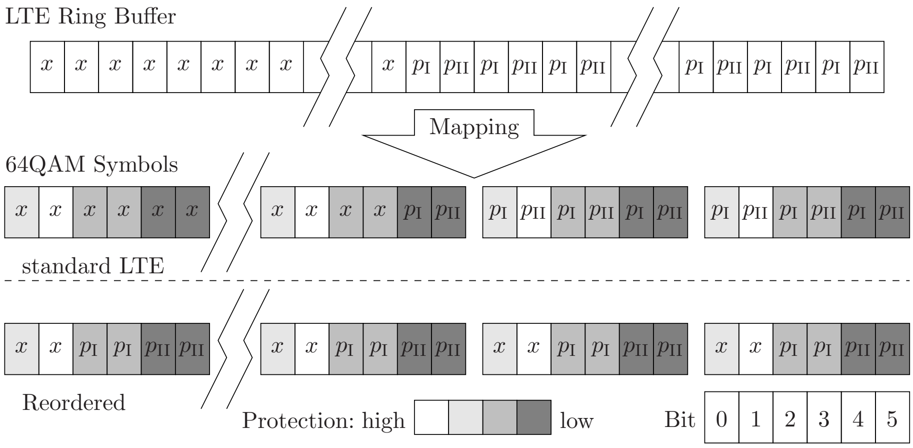


Figure 3. Standard LTE and reordered mapping of encoded bits to complex 64QAM symbols.

of a fixed number of turbo decoding and channel estimation iterations. In LTE, the unequal error protection property present in the complex signal constellations is not taken into account. This motivates us to propose the following approach to exploit this UEP property: By a simple reordering of the encoded bits, systematic bits are placed in the well protected positions of the complex signal constellation symbol while the parity bits are asymmetrically placed in the less protected positions.

This scheme is depicted in Fig. 3: With rate-$\frac{1}{3}$ coding the data bits are encoded to become the systematic bits $\underline{x}$ with their corresponding parity bits $\underline{p}_{\mathrm{I}}$ and $\underline{p}_{\mathrm{II}}$ (cf. Fig. 1). In the standard LTE system these bits are sequentially read out of the ring buffer and mapped to the 6 bit positions of the 64QAM symbol resulting in complex modulation symbols that either consist of 6 systematic bits x or of 6 parity bits p_{I} and p_{II} (with the possible exception of one symbol consisting of both types of bits). In our proposed reordering, the bits are mapped according to the levels of protection illustrated by Fig. 2: The systematic bits $\underline{x}$ are mapped to Bits 0 and 1 of the constellation symbol, the parity bits $\underline{p}_{\mathrm{I}}$ of the first constituent encoder of the PCCC are mapped to Bits 2 and 3 respectively, leaving Bits 4 and 5 for the parity bits $\underline{p}_{\mathrm{II}}$ of the second constituent encoder. In that way the systematic bits obtain the highest level of protection while the parity bits $\underline{p}_{\mathrm{II}}$ are most error-prone. The implications of this UEP scheme are explained in the following section.

4. Simulation Results

To illustrate the impact of our modified mapping scheme we first depict in Fig. 4 the average mutual information $\mathcal{I}$ obtained by the systematic and parity bits of both constituent encoders and compare it to the average mutual information of all coded bits obtained for the standard LTE system. Obviously, the average of the mutual information obtained by systematic and parity bits of the proposed scheme equals the average mutual information obtained for standard LTE. Furthermore, the average mutual information of $\underline{p}_{\mathrm{I}}$ corresponds to the curves for Bit 2

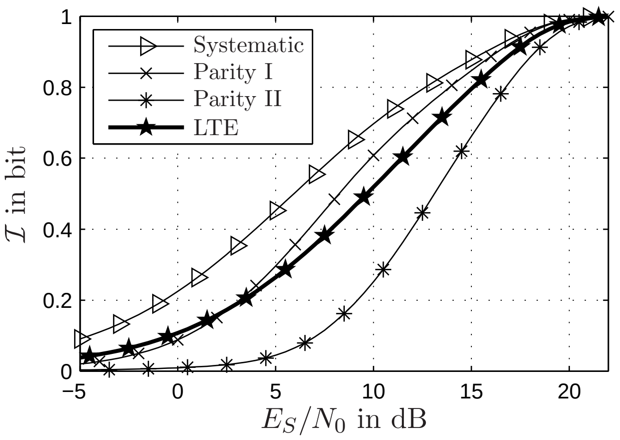
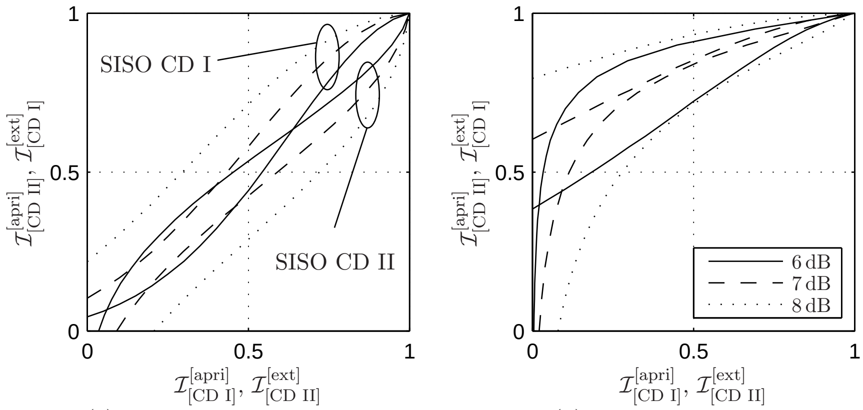


Figure 4. Average mutual information $\mathcal{I}$ for transmitted systematic and parity bits using the proposed scheme compared to the average mutual information for all transmitted bits in standard LTE versus channel quality.



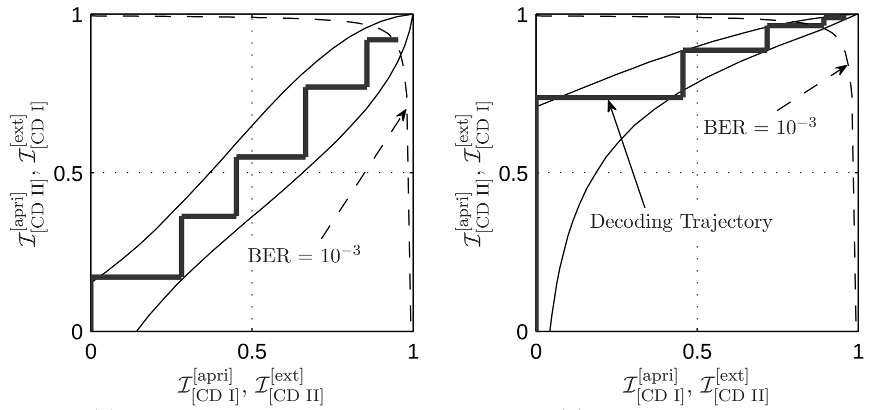
(a) standard LTE mapping (b) reordered mapping

Figure 5. EXIT characteristics of the SISO component decoders for different channel qualities.

and 3 of the 64QAM symbol while the average mutual information of $\underline{p}_{\mathrm{II}}$ corresponds to the curves for Bit 4 and 5 (cf. Fig. 2). The quintessence in Fig. 4, however, is the significance of the unequal error protection of systematic and the two different types of parity bits in the proposed scheme.

This fact is illustrated even more vividly by the Extrinsic Information Transfer (EXIT) characteristics [5] which describe the amount of extrinsic information $\mathcal{I}^{[\mathrm{ext}]}$ obtained from a SISO decoding unit given a certain amount of a priori information $\mathcal{I}^{[\mathrm{apri}]}$. The EXIT characteristics of the two component SISO channel decoders exchanging extrinsic information in a turbo decoding process in one EXIT chart give a distinct impression of the convergence behavior of this iterative decoding process. For a detailed description of EXIT analysis the reader is referred to [5].

Figure 5 compares the characteristics of SISO CD I and SISO CD II obtained from simulations of the proposed system to those obtained from simulations of standard LTE under different channel conditions. The difference is evident: While in the standard LTE case in Fig. 5(a) the EXIT characteristics of both SISO CDs show the expected symmetric behavior, the proposed reordering of bits leads to highly asymmetric characteristics, i.e., SISO CD I and SISO CD II yield different transfer functions leading to a different convergence behavior (cf. Fig. 5(b)). The higher protection of its parity bits $\underline{p}_{\mathrm{I}}$ enables SISO CD I to produce a high amount of extrinsic information $\mathcal{I}^{[\mathrm{ext}]}_{[\mathrm{CD\ I}]}$ in the initial decoding step, i.e., for $\mathcal{I}^{[\mathrm{apri}]}_{[\mathrm{CD\ I}]} = 0$. Contrary, SISO CD II suffers from its less protected par-



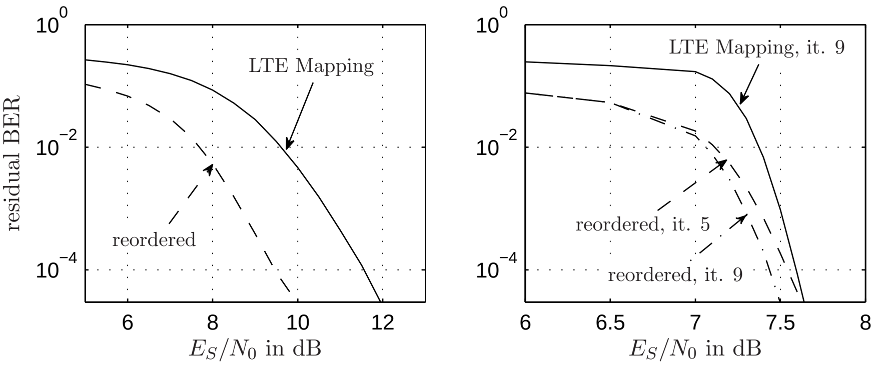
(a) standard LTE mapping (b) reordered mapping

Figure 6. EXIT characteristics of the SISO component decoders and decoding trajectory for $E_S/N_0 = 7.5\,\text{dB}$.

ity bits $\underline{p}_{\text{II}}$ which results in a poor performance, i.e., $\mathcal{I}^{[\text{ext}]}_{[\text{CD II}]}(\mathcal{I}^{[\text{apri}]}_{[\text{CD II}]} = 0)$ is very low for the initial decoding step. However, such an initial decoding step without a priori information is never executed by the second decoder in a parallel turbo decoding structure: SISO CD II will always perform its first decoding step with a priori knowledge obtained from the initial decoding of SISO CD I.

Recording and averaging the mutual information during simulations of both systems for a SNR of 7.5 dB enables the plotting of the staircase-like decoding trajectories depicted in Fig. 6. These trajectories confirm the above statements for the depicted case: As the trajectory of the system with reordered bit mapping in Fig. 6(b) reaches further to the right after the first complete turbo decoding iteration, i.e., the first stair step, compared to the standard LTE system in Fig. 6(a), a better BER performance for the non-iterative case can be predicted. Furthermore, while in case of standard LTE approximately 5 turbo decoding iterations are necessary to reach a residual bit error rate of 10^{-3} depicted by the dashed line in both subplots, only 3 such iterations suffice in the modified system. This behavior indicates a faster convergence speed of the system with reordered mapping.

Both predictions, the better performance in the non-iterative case, as well as the faster convergence are backed by the simulation results given in Fig. 7: For the non-iterative case depicted in Fig. 7(a) the proposed mapping yields an SNR gain of approximately 2 dB over the standard LTE system. For the iterative system on the other hand, the BER performance of standard LTE with 9 turbo decoding iterations is already

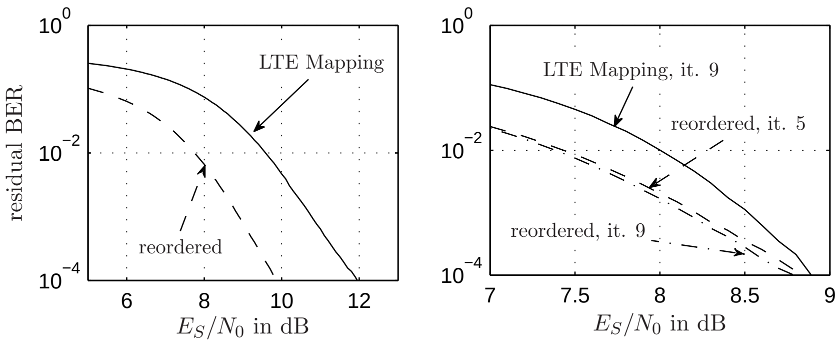


(a) non-iterative decoding (b) iterative decoding

Figure 7. Residual BER for standard LTE mapping and the proposed reordered mapping with non-iterative and iterative decoding, block length: 6144 data bits.

reached or even outperformed after 5 iterations with the proposed reordering, cf. Fig. 7(b). Note that we do not claim a superiority in terms of residual BER of either one of the systems after convergence.

So far we used the maximum allowed block length of 6144 data bits for all simulations. However, it is a well known fact, that the code block length influences the performance of a turbo coded system: For small code block lengths the system converges earlier than predicted by the intersection of the decoder characteristics in the EXIT chart which leads to a degradation in BER performance. That is why we give an example for the BER performance of a system with a block length of 280 data bits in Fig. 8. For the non-iterative case depicted in Fig. 8(a) the same SNR gain between standard LTE mapping and the proposed reordered map-



(a) non-iterative decoding (b) iterative decoding

Figure 8. Residual BER for standard LTE mapping and the proposed reordered mapping with non-iterative and iterative decoding, block length: 280 data bits.

ping is observed although the absolute performance decreases slightly. As expected, the BER performance of both systems with iterative decoding is reduced due to the smaller code block length. Therefore, the advantage in the convergence behavior of the modified system appears smaller, but is nevertheless still visible.

5. Conclusion

In this contribution we illustrated the employment of UEP inherent in 64QAM Gray signalling by slightly modifying the mapping of coded bits to complex 64QAM symbols in a UMTS LTE system. It is shown that for rate-$\frac{1}{3}$ coding SNR gains of approximately 2 dB can be achieved for non-iterative decoding while a significant reduction of turbo decoding iterations (44 % in the given example) can be obtained for iterative systems. Basis is the unequal error protection of the parity bits of the two constituent encoders employed in LTE leading to an advantageous convergence behavior which has been analyzed using EXIT charts. Simulations have been conducted using an CAWGN channel model. Complex channel models like flat fading Rayleigh channels or time-variant frequency selective fading channels are currently considered.

Acknowledgment

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References

[1] 3GPP TS 36.211. Evolved Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation. Version 8.2.0, 3GPP Technical Specification, 2008.

[2] 3GPP TS 36.212. Evolved Terrestrial Radio Access (E-UTRA); Multiplexing and Channel Coding. Version 8.2.0, 3GPP Technical Specification, 2008.

[3] J. Cheng, A. Nimbalker, Y. Blankenship, B. Classon, and T. Blankenship. Analysis of Circular Buffer Rate Matching for LTE Turbo Code. In *Proceedings of IEEE Vehicular Technology Conference (VTC-Fall)*, Calgary, Canada, Sept. 2008.

[4] P. Robertson, E. Villebrun, and P. Hoeher. A Comparison of Optimal and Sub-Optimal MAP Decoding Algorithms Operating in the Log Domain. In *Proc. IEEE Int. Conf. Commun. (ICC)*, pages 1009–1013, Seattle, USA, 1995.

[5] S. ten Brink. Convergence Behaviour of Iteratively Decoded Parallel Concatenated Codes. *IEEE Transactions on Communications*, October 2001.

[6] S. Godtmann, H. Lüders, G. Ascheid, and P. Vary. A Bit-Mapping Strategy for Joint Iterative Channel Estimation and Turbo-Decoding. In *Proceedings of IEEE Vehicular Technology Conference (VTC-Fall)*, Calgary, Canada, September 2008.