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Turbo equalization receivers for evolved GSM/EDGE radio access network using QAM modulation

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ABSTRACT

For evolution of the GSM/EDGE radio access network (RAN), the use of higher order modulation like 16- and 32-ary quadrature amplitude modulation (QAM) is considered in standardization for increased peak data rates and reduced transmission delays. In this paper, an optimized receiver design for different packet data transmission schemes is proposed. Turbo coding and turbo equalization is discussed for improved power efficiency and interference robustness. An efficient complexity reduction of the equalizer enables the usage of turbo equalization at a complexity comparable to that of separate equalization and decoding for turbo-coded transmission.

1. Introduction

In order to increase the peak data rates and to reduce transmission delays in the GSM/EDGE system, higher order modulation like 16- and 32-ary quadrature amplitude modulation (QAM) and double (dual) symbol rate (DSR) [1] are currently discussed for standardization [2]. In this paper, we focus on higher order QAM modulation, but the results can also be extended to DSR in a straightforward way. Furthermore, an extension of channel coding in GSM/EDGE[1] is discussed currently based on turbo coding of UMTS Terrestrial Radio Access Network (UTRAN) [3].

A performance analysis of turbo-coded transmission with 16QAM can be found in [4], where in addition the influence of transmission impairments on the performance as well as the gain in terms of network throughput is shown. In this paper, we investigate turbo equalization [5] applied to the conventional convolutionally coded transmission schemes as competitor for the turbo-coded transmission schemes, and compare performance of different reduced-complexity (inner) equalizers[2] for the 16QAM and 32QAM packet data transmission schemes. An advantage of the turbo equalization approach is, that the conventional coding format can be preserved, so that even conventional receivers (separate equalization and decoding) are applicable in the system. Optionally, the receiver may apply a varying number of equalization and decoding iterations, depending on the signal quality (e.g. signal-to-interference-plus-noise ratio (SINR)).

Several turbo equalization schemes for time division multiple access (TDMA) systems based on PSK modulation can be found in the literature, e.g. [7–14]. For turbo equalization, the (inner) equalizer receives extrinsic a priori information input from the outer channel decoder and provides extrinsic a posteriori information output to the decoder. The decoder processes the input from the equalizer and produces extrinsic a posteriori information on

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[1] Convolutional codes of constraint length $K = 7$ are employed for GSM/EDGE modulation and coding schemes (MCSs) with 8-ary phase-shift keying (PSK) modulation.

[2] As the overall equalization process is comparable to the decoding of serially concatenated convolutional codes (SCCCs) [6] (regarding the ISI channel as inner code), we refer to the equalizer as the inner component of the turbo receiver [5].

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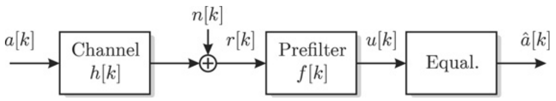

Fig. 1. System model with transmit signal $a[k]$ and received signal $r[k]$.

the coded bits, so that equalization performance improves from iteration to iteration. As (inner) equalizer, reduced-complexity variants of the BCJR algorithm [15–17] are selected, which are based on joint reduced-state sequence estimation (JRSSE) with Ungerboeck set partitioning [18]. We show that a large complexity reduction (compared to the full-state equalizer) is feasible, similar to 8PSK modulation [19]. Furthermore, a simplified minimum mean-squared error (MMSE) soft-output detector [7–10] with soft cancellation of pre- and postcursor intersymbol interference (ISI) extended to higher order modulations can be applied for subsequent turbo equalization iterations. For some of the transmission schemes considered, extrinsic information transfer (EXIT) chart [20] convergence analyses are performed.

The paper is structured as follows. The system model is introduced in Section 2, and the receiver equalization algorithm is presented in Section 3. In Section 4, performance is analyzed and simulation results are given for all currently considered GSM/EDGE modulation and coding schemes (MCSs).

2. System model

The system model in equivalent discrete-time complex baseband representation is shown in Fig. 1. After encoding of the source information bits $d_s[k'']$ and successive interleaving, the encoded bits $d[k']$ are mapped to linear modulation symbols $a[k]$ and 4 bursts[3] of $N_S = 120$ symbols each are transmitted over the channel with impulse response $h[k]$ of order q_h, which includes transmit pulse shaping and receive filtering (square-root raised cosine filter, roll-off factor $\alpha = 0.3$ [19]). As ideal frequency hopping is assumed, uncorrelated channel realizations are present for different bursts (block fading channel). The receive signal $r[k]$ is disturbed by additive white Gaussian noise (AWGN) $n[k]$ with variance σ_n^2. The MMSE decision-feedback equalization (DFE) prefilter of [21] with impulse response $f[k]$ is employed in front of reduced-complexity BCJR equalization, whereas for soft-output detection with soft ISI cancellation the matched filter is used. Turbo equalization is based on sequence $u[k]$ and delivers estimates of the transmit symbols $\hat{a}[k]$ and the transmitted information bits $\hat{d}_s[k'']$.

2.1. Coding and Interleaving

2.1.1. Turbo coding

In [2], the usage of the UMTS UTRAN turbo code [3] is proposed, which is also adopted here with according internal interleaver and rate matching.

[3] For some MCSs of GSM/EDGE, code blocks comprise 2 bursts instead of 4 (default value).

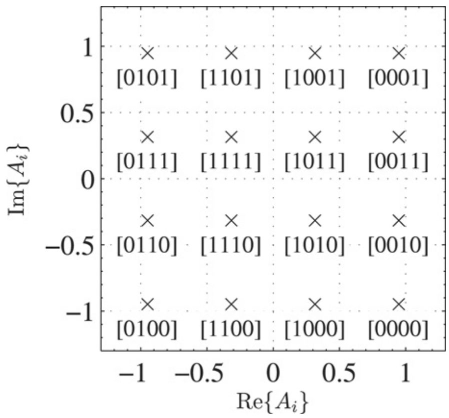

Fig. 2. 16QAM constellation and mapping of 4-tuple $\left[d_0^{(i)}\, d_1^{(i)}\, d_2^{(i)}\, d_3^{(i)}\right]$.

2.1.2. Convolutional coding

For all transmission schemes with convolutional coding, the rate 1/3 convolutional basis code (constraint length $K = 7$) of GSM/EDGE [22] with appropriate puncturing is applied.

2.1.3. Interleaving

A block interleaver has been adopted for all transmission schemes without precoding (cf. Section 2.2). Only for precoded transmission, the S-random interleaver [23] is used in order to optimize performance [5].

2.2. Precoding and mapping

The adopted mapping for 32QAM is given in [2]. As no explicit mapping is specified for 16QAM in the standard so far, we adopt the Gray mapping shown in Fig. 2 with 4-tuples $\mathbf{d}^{(i)} = \left[d_0^{(i)}\, d_1^{(i)}\, d_2^{(i)}\, d_3^{(i)}\right]^{\mathrm{T}}$ ($(\cdot)^{\mathrm{T}}$: transposition). The modulation alphabet is denoted as $\mathcal{A} = \{A_i \mid i = 0, \ldots, N_A - 1\}$ consisting of $N_A = 2^{q_a}$ modulation symbols A_i with arbitrary numbering, where q_a is the number of bits carried by the transmit symbols. The bit sequence $d[k']$ is mapped to the vector-valued sequence $\mathbf{d}[k]$ with $[\mathbf{d}[k]]_j = d[kq_a + j]$ for $k \in \mathcal{K} = \{0, \ldots, N_S - 1\}$ and $j \in \mathcal{J} = \{0, \ldots, q_a - 1\}$, where $[\cdot]_m$ denotes the mth element of a column vector, and finally the transmit symbol A_i for which $\mathbf{d}[k] = \mathbf{d}^{(i)}$ is fulfilled is selected for $a[k]$, if no precoding is applied.

A comprehensive study of turbo equalization is given e.g. in [5] (and references therein), where it is demonstrated that EXIT charts [20] may be used in order to optimize (turbo equalization) detection performance for static frequency-selective channels with Gaussian disturbance by fitting the according equalizer and decoder characteristics.

As turbo equalization schemes are comparable to the decoding of serially concatenated convolutional codes (SCCCs), the inner code should have a recursive structure in order to optimize the error probability of the turbo receiver in the water-fall region [6]. This can be