SPACE-TIME UMTS-FDD RECEIVER WITH WEIGHTED INTERFERENCE CANCELLATION

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ABSTRACT

This contribution investigates a space-time multiuser receiver with weighted non-linear parallel interference cancellation for the uplink of UMTS FDD mode. More specifically, we tailor a receiver concept originally proposed by Divsalar et al. to the uplink of UMTS FDD and extend the concept to space-time processing. This receiver consists of several concatenated identical processing stages. The concept turns-out to be well-suited for the uplink which employs long-code CDMA. Our simulations show that this receiver offers a graceful trade-off between computational complexity (expressed in the number of stages) and bit error rate in UMTS. With pilot-based channel estimation, four receive antenna elements, and two receiver stages we obtain an uncoded bit error rate of 4% at an E_b/N_0 of 4 dB.

1. INTRODUCTION

Multistage receivers with *parallel interference cancellation* (PIC) offer a graceful degradation in bit error rate when traded against signal processing complexity. Moreover, they are well-suited for long-code CDMA systems like the uplink of UMTS FDD [4,5]. Introducing space-time signal processing allows further enhancements of the multistage concept.

An approximate analysis of receiver structures with PIC based on signal to interference and noise ratio computation (but ignoring correlation effects between stages) can be found in [1,6]. An analysis which takes correlation effects into account can be found in [2,8]. However, these analytical results turn-out to be rather in-accurate, especially for higher numbers of stages, due to the required idealizations.

To the knowledge of the authors, an accurate theoretical analysis of non-linear PIC receiver structures enjoying lower bit error rates than linear PIC structures does not yet exist in the literature. We describe simulations for finding the best set of PIC weighting coefficients for a given number of users K and a selected E_b/N_0. Finally, we discuss effects from imperfect channel estimation based on pilot symbols on the Physical Control CHannel (DPCCH) on the bit error rate performance.

2. SYSTEM MODEL

We consider the uplink of a UMTS FDD cell with K users [4,5] illustrated in Fig.2. Dedicated channels are segmented in time into frames with a duration of 10 ms. Each frame consists of 15 slots with 2560 chips each and has user data modulated on the inphase path and user control information mapped onto the quadrature path. The data a_k of the k-th user is spread with the channelization code $c_{\mathrm{DCH},k}$ that has a sequence length $N_{\mathrm{DCH},k} \in \{8,16,32,64, 128,256\}$ chips with 1 data channel, or $N_{\mathrm{DCH},k} = 4$ with up to 6 parallel data channels. The control channel contains the pilot symbols, the *transport format combination indicator* (TFCI), the *transmit power control command* (TPC), and *feedback information* (FBI) in $d_{\mathrm{CCH},k}$. The corresponding channelization code $c_{\mathrm{CCH},k}$ has spreading factor $N_{\mathrm{CCH}} = 256$ in any case. Let n be the chip sampling time then

$$\begin{aligned} x_k[n] \quad &= \quad a_k\left[\lceil n/N_{\mathrm{DCH},k}\rceil\right] c_{\mathrm{DCH},k}\left[n \bmod N_{\mathrm{DCH},k}\right] \\ &\quad + jb_k\left[\lceil n/N_{\mathrm{CCH}}\rceil\right] c_{\mathrm{CCH},k}\left[n \bmod N_{\mathrm{CCH}}\right] \end{aligned}$$

with $\lceil\cdot\rceil$ being the integer ceil operator. To distinguish among users the information is chip-wise multiplied (scrambled) by a finite segment taken from a Gold-sequence s_k of length 38400 chips (1 frame)

$$x'_k[n] = x_k[n] s_k[n \bmod 38400].$$

The transmitted signal of each user is subject to frequency selective fading on a *multiple-input multiple-output* (MIMO) channel. We assume a block-fading characteristic for the duration of a slot period. In the system under consideration we have $N_T = 1$ transmit antenna (for each mobile user individually) and N_R receive antennas at the Node B. Assuming that the k-th user has L_k channel taps, the *channel impulse response* (CIR) to the r-th receive antenna-element is given by

$$h_{r,k}[n] = \sum_{\ell=1}^{L_k} h_{r,k}[\ell]\,\delta[n-\tau_{\ell,k}].$$

The tap delays $\delta[n-\tau_{l,k}]$ for user k are assumed to be the same on all antennas elements. The individual channel taps $h_{r,k}[\ell]$ are i.i.d. with zero mean and variance $\sigma^2_{\mathrm{h},k} = 1/L_k$. We follow [3] and normalize the channel taps of user k over all antennas to unit power,

$$\mathbb{E}\left\{\sum_{r=1}^{N_R}\sum_{\ell=1}^{L_k}\left|h_{r,k}[\ell]\right|^2\right\} = 1. \qquad (1)$$

The contributions of individual users ($k = 1,\ldots,K$) add up on the multiuser MIMO channel:

$$y_r[n] = \sum_{k=1}^{K} A_k x'_k[n-\nu_k] * h_{r,k}[n] + v[n]\;, \qquad (2)$$

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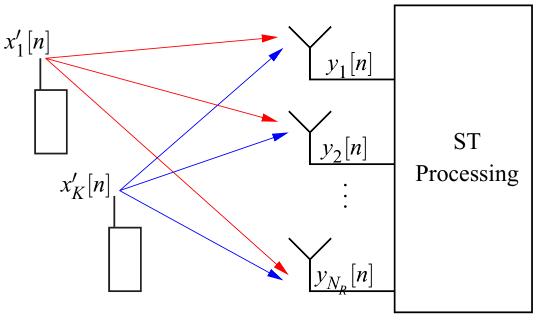

Figure 1: System setup with space-time receiver.

where $*$ stands for the convolution. $v[n]$ denotes the additive complex white Gaussian noise with variance $\sigma_v^2 = 1$. The receive power of the k-th user is denoted by A_k^2 and ν_k designates the propagation delay of the earliest arrival for user k. This formulation describes the asynchronous uplink.

3. MULTISTAGE RECEIVER

Let $\boldsymbol{y}_{k,r}[m]$ be the received signal vector at the r-th antenna which contains energy from the m-th symbol of user k. We can then apply a single-user matched filter $\boldsymbol{f}_{k,r}[m] = \boldsymbol{h}_{k,r} * (c_{\mathrm{DCH},k}[m] \odot s_k[m])$ to the receive vector to obtain the m-th data symbol estimate of the k-th user:

$$\tilde{a}_k^{(1)}[m] = \frac{1}{N_R} \sum_{r=1}^{N_R} \boldsymbol{f}_{k,r}^{\mathrm{H}}[m] \boldsymbol{y}_{k,r}[m]. \qquad (3)$$

Note that $\odot$ designates the element-wise multiplication of the data channelization sequence with the corresponding part of the scrambling sequence. The signalling data on the quadrature component is processed accordingly.

Without loss of generality, we assume below that user 1 is the user of interest and the remaining users $2, \ldots, K$ are the interferers. For suppressing *multiple access interference* (MAI), the estimated symbols of the interferers are respread and used for estimating the MAI for user 1, cf. [9]. The resulting MAI estimate at sample m is subtracted from the observation vector $\boldsymbol{y}_{1,r}[m]$. Here, we investigate a weighted *parallel interference canceller* (PIC) specifically for UMTS similar to [1] which is shown in Fig. 3. The combination of a bank of Rake receivers and the weighted PIC is called a *stage* for the purposes of this paper. The symbol estimates from the first stage ($i = 1$) are defined in Eq.(3). In the i-th stage (for $i = 2, 3, \ldots$), the estimated MAI for user 1 is weighted by p and the symbol estimate $\tilde{a}_1^{(i-1)}[m]$ from the previous stage $i-1$ is weighted by $(1-p)$,

$$\tilde{a}_1^{(i)}[m] = (1-p)\,\tilde{a}_1^{(i-1)}[m] + p\,\boldsymbol{f}_{1,r}^{\mathrm{H}}[m] \left(\boldsymbol{y}_{1,r}[m] - \sum_{\ell=2}^{K} \hat{a}_\ell^{(i-1)}[m] \boldsymbol{f}_{\ell,r}[m] \right) . \qquad (4)$$

where the MAI contribution from the ℓ-th interferer is estimated by a suitably chosen mapping g,

$$\hat{a}_\ell^{(i-1)}[m] = g\left(\tilde{a}_\ell^{(i-1)}[m] \right) .$$

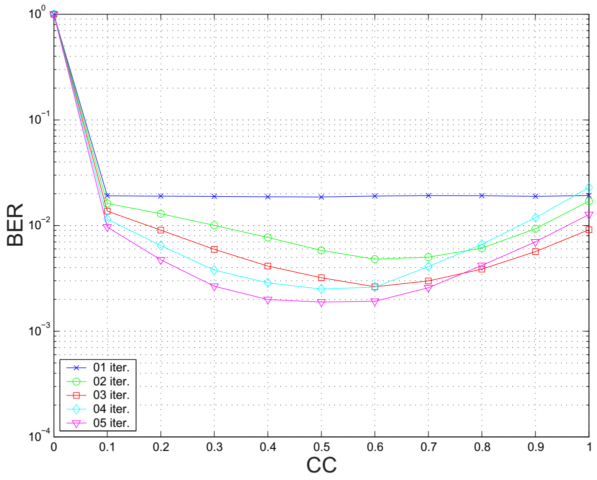

Figure 3: BER evolution vs. weight factor p in case of the *linear* partial IC device. $K = 10$, $N_{\mathrm{DCH}} = 32$, AWGN channel.

The mapping functions considered in this contribution are the trivial mapping $g(\tilde{a}) \stackrel{\triangle}{=} \tilde{a}$, the MMSE estimate for BPSK modulation on AWGN channels [7], i.e. $g(\tilde{a}) \stackrel{\triangle}{=} \tanh(\tilde{a}/c)$, and the ML estimate $g(\tilde{a}) \stackrel{\triangle}{=} \mathrm{sign}(\tilde{a})$. The trivial mapping and the MMSE estimator are soft-symbol estimators while the ML estimate carries out hard decisions. The c-parameter of the MMSE estimator adjusts the reliability of the symbol. If the MAI variance σ_z^2 were known [7] then the MMSE estimator would have used $c = \sigma_z^2/a$. Instead of the true σ_z^2, we use the estimate

$$\hat{\sigma}_z^{(i)} = \left| \frac{1}{M} \sum_{i=1}^{M} (\tilde{a}^{(i)})^2 - a^2 \right|^{\frac{1}{2}} ,$$

in the i-th stage. Divsalar et al. [1] report that the best performance is achieved with a $\tanh(\cdot)$ mapping.

4. CHOICE OF THE WEIGHTS

An accurate theoretical analysis of the multistage receiver with non-linear mapping g is not known to the authors. Therefore, we investigate the influence of the weighting p in Eq.(4) through simulations and search for optimal p numerically.

The strategy is to find the factor p for which the BER becomes minimum for a given E_b/N_0 and a system load α. This is not yet known in the literature for the tanh-mapper we will derive these and compare them with the corresponding results of the linear mapper.

For the current analysis we have $K = 10$ users and all have $N_{\mathrm{DCH}} = 32$. We assume a AWGN channel with an E_b/N_0 of 8 dB. The dependency of the bit error rate on the weighting is depicted in Fig. 3 for the linear canceller. The non-linear canceller weights are depicted in Fig.4 for the sign mapper and in Fig.5 for the tanh mapper.

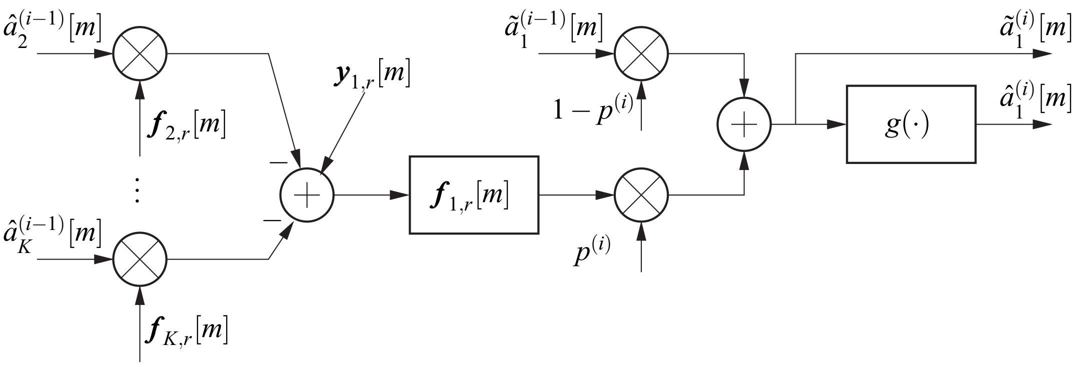

Figure 2: i-th receiver stage for user 1 formulated in Eq.(4). The users $2,\ldots,K$ are interferers.

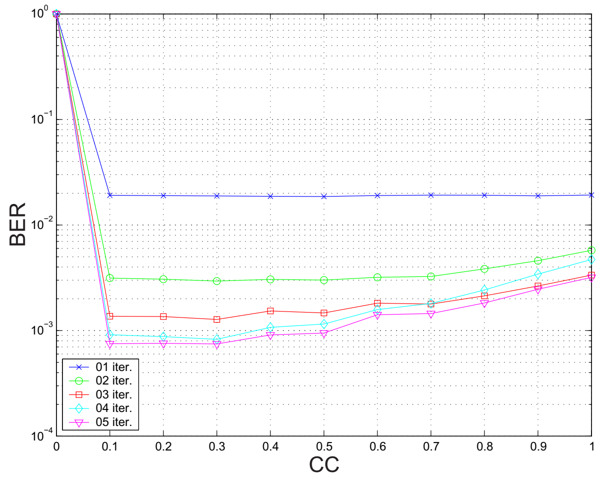

Figure 4: BER evolution vs. weight factor p in case of the *sign* partial IC device. $K = 10$, $N_{\text{DCH}} = 32$, AWGN channel.

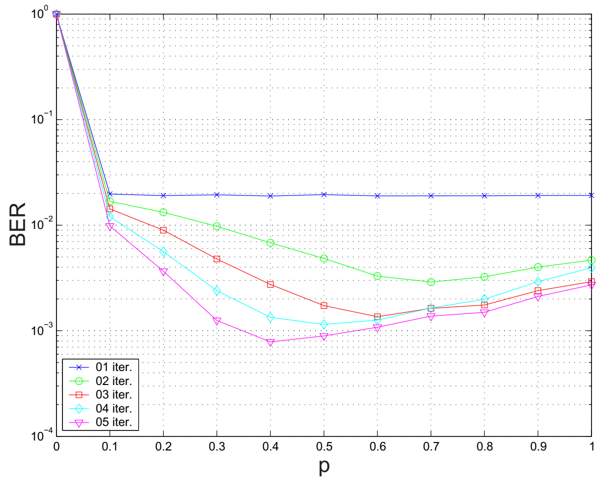

Figure 5: BER evolution vs. weight factor p in case of the *tanh* partial IC device. $K = 10$, $N_{\text{DCH}} = 32$, AWGN channel.

5. SIMULATION RESULTS

In this section we discuss the performance of the space-time multistage non-linear weighted PIC receiver and compare it to the corresponding linear version. We consider a system with $K = 10$ users with spreading factor $N_{\text{DCH}} = 32$ on the data channel. The slot format was chosen to have $P = 8$ pilot symbols on the dedicated control channel of each user. The k-th user is assigned the long uplink scrambling sequence #k, cf. [5]. The propagation channels have a delay spread of $\max\{\tau_k\} = 15$ chips and there are $L_k = 4$ *temporal* i.i.d. Rayleigh taps generated for each link under the restriction formulated in Eq.(1). The path searcher in the Node B considers $N_f = 4$ Rake fingers. We observed in simulations that the sign mapping leads to the best performance and we will focus on this case with the weights as $\boldsymbol{p} = [0.30.50.7]$, where the first entry denotes the weight for the first stage and so forth.

First we consider the perfect channel estimation case. This scenario is depicted in Fig. 6. We see that with merely three stages the receiver can gain considerably in bit error rate compared to the one-shot RAKE case which corresponds to the first stage only. For comparison we have also plotted the single user bound. In the case of $N_R = 4$ we can reach the single user bound.

The impact of imperfect channel estimation is shown in Fig. 7. At a typical E_b/N_0 of 4 dB the gap to the single user bound is 1.5 dB in the case of single antenna reception and reduces to 0.5 dB for a four antenna space-time processor. In the high SNR regime the gap becomes larger: at 8 dB we loose a factor 4 in bit error rate for the single antenna system whereas it reduces to a factor of 2 in the four element case.

6. CONCLUSIONS

This contribution investigates the benefits from partial interference cancelling for a space-time UMTS FDD receiver. The symbol decisions are taken with either linear or non-linear devices, namely a hard-limiter and a hyperbolic tangent. We have carried out numerical simulations for finding suitable weights. We compare the resulting receiver variants in terms of their bit error rates. It turns out that the hard-limiting decision leads to best performance. For this variant we discuss results in a multipath environment and one or

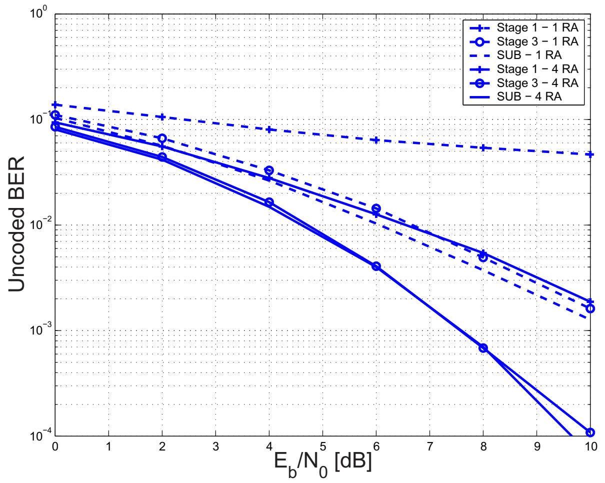

Figure 6: Partial IC with sign device and perfect CSI. $K = 10$, $N_{\text{DCH}} = 32$, $\max\{\tau_k\} = 8$ chips, $L_k = 4$.

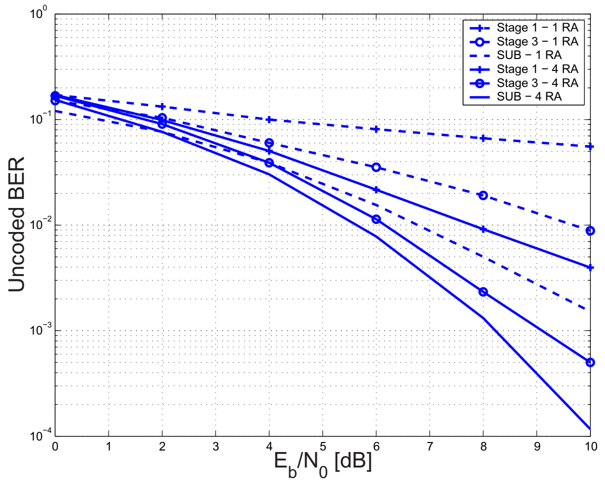

Figure 7: Partial IC with sign device and channel estimation. $K = 10$, $N_{\text{DCH}} = 32$, $\max\{\tau_k\} = 8$ chips, $L_k = 4$.

four receive antennas. We investigate the loss from imperfect channel estimation based on the correlation with respect to perfect channel state information at the receiver. It turns out that the benefit from multistage processing improves with E_b/N_0 is. A factor of 6 in BER reduction is observed at 10 dB for the single antenna receiver. With four receive antennas, the factor increases to 8.

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