ITERATIVE CHANNEL ESTIMATION FOR UTRA/FDD UPLINK WITH POWER RATIO ADAPTION

S. Saur[1], H. T. Hagmeyer[1], J. Speidel[1], V. Braun[2] and C. Hoek[2]
[1]Institute of Telecommunications, University of Stuttgart, Germany
[2]Alcatel R&I, Stuttgart, Germany
Email: {saur, speidel, hagmeyer}@inue.uni-stuttgart.de, {Volker.Braun, Cornelis.Hoek}@alcatel.de

Abstract

We present an iterative receiver for the Universal Terrestrial Radio Access (UTRA) uplink connection in Frequency Division Duplex (FDD) mode. Base station (Node B) operates with two space diversity receive antennas. In contrast to a conventional receiver, which only uses the Dedicated Physical Control Channel (DPCCH) for channel estimation, we have established an outer iteration feedback loop from the Turbo decoder output to the channel estimator. Various concepts to exploit both DPCCH and the Dedicated Physical Data Channel (DPDCH) for an improved iterative channel estimation are investigated. Moreover, for a given total number of iterations, we have found a good compromise between the number of Turbo decoder iterations and those of the outer feedback loop. It is shown that the proposed receivers can reduce the block error ratio (BLER) significantly compared to conventional solutions without feedback for fast moving user equipment (UE). Furthermore, the performance is clearly increased by optimizing the DPCCH-to-DPDCH power ratio.

I. Introduction

Each UMTS uplink radio link is equipped with a Dedicated Physical Control Channel (DPCCH) that contains a pilot pattern which may be utilized at the receiver for channel estimation and signal-to-interference ratio (SIR) estimation. The DPCCH is code multiplexed with the user data (DPDCH). Thus a certain portion of the entire transmit power is reserved for control information.

The performance of the receiver strongly depends on the DPCCH-to-DPDCH power ratio

$$\gamma = 10 \log \frac{\text{DPCCH power}}{\text{DPDCH power}}. \qquad (1)$$

If γ is large, channel estimation performs well. However the DPDCH suffers from a low signal-to-noise ratio (SNR) and vice versa.

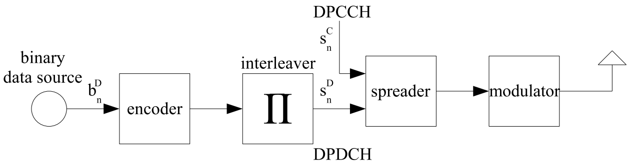

Figure 1: Transmitter

We investigate a Node B receiver that can also use the DPDCH to improve channel estimation. Therefore, the output of the Turbo decoder providing a posteriori L-values of the information bits is fed back to the channel estimator. With this arrangement the first pilot based channel estimation is refined by the fed back sequence. We call this procedure outer iteration compared to the inner iteration done by the Turbo decoder. It will be shown that the number of outer and inner iterations as well as γ will affect the receiver performance.

II. System model

A. Transmitter

Figure 1 shows the transmitter of the link. It consists of the binary data source with information bits b_n^D, rate 1/3 recursive systematic Turbo encoder, interleaver, spreader and modulator according to [1] and [2]. n is discrete time given by the bit clock. We denote the inputs to the spreader with s_n^D (DPDCH) and s_n^C (DPCCH), respectively. The output of the spreader is a code multiplexed complex chip sequence.

B. Channel

We assume a multi-path fading channel with propagation conditions given in [3] with additive white Gaussian noise (AWGN) n_n. Each path is represented by Rayleigh distributed channel coefficients α_n. Table 1

Table 1: Propagation conditions of the multi-path fading channel

Relative path delay [ns]	0	260	521	781
Average attenuation [dB]	0	3	6	9

shows the parameters that we have used for the simulations.

C. Receiver

The investigated Node B receiver with outer iteration is depicted in Figure 2. Only one RAKE finger is illustrated. In general, the path searcher provides one sequence of complex chips per detected finger. We assume ideal path searching, i.e. the RAKE receiver finds the right number of propagation paths and their delays. The despreader separates the samples

$$r_n^D = \alpha_n s_n^D + n_n \quad \text{(DPDCH) and} \tag{2}$$

$$r_n^C = \alpha_n s_n^C + n_n \quad \text{(DPCCH).} \tag{3}$$

r_n^C are input to the channel estimator that provides estimates $\hat{\alpha}_n$ of the channel coefficients α_n. The maximum ratio combiner compensates the channel and adds the finger signals up that were detected by the path searcher. After deinterleaving, Turbo decoding and hard decision estimates $\hat{b}_n^D$ of the sent bit sequence b_n^D are available. The outer iteration loop allows to refine the channel estimates $\hat{\alpha}_n$. Therefore a re-encoder, an interleaver and a buffer for the samples r_n^D are required.

III. Channel estimation

At the receiver the channel coefficients are estimated for each path separately. According to [3] a pilot bit s_n^c is affected by the Rayleigh fading coefficient α_n and additive white Gaussian noise (AWGN) n_n.

As the pilot bits $s_n^C \in \{\pm 1\}$ are known at the receiver we can find estimates $\hat{\alpha}_{0,n}$ of α_n as

$$\hat{\alpha}_{0,n} = \frac{1}{N} \sum_{i=n-N_b}^{n+N_f} r_i^C s_i^C =$$

$$= \frac{1}{N} \sum_{i=n-N_b}^{n+N_f} \alpha_i + \frac{1}{N} \sum_{i=n-N_b}^{n+N_f} n_i s_i^C \tag{4}$$

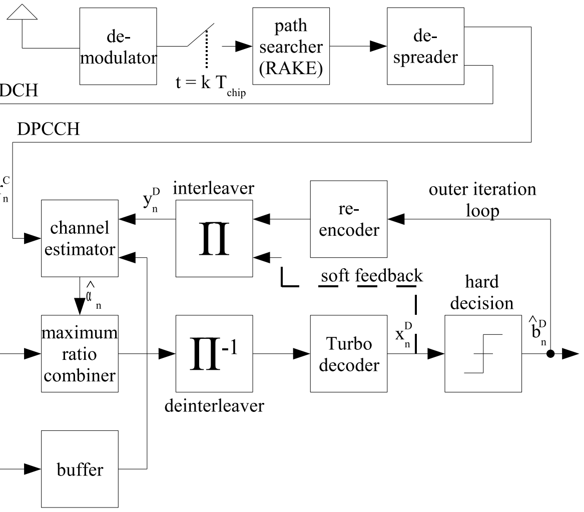

Figure 2: Node B receiver with outer iteration loop

where $N = N_b + N_f + 1$ is the number of considered pilot bits. N_b samples are taken from the past and N_f from the future. Index 0 in $\hat{\alpha}_{0,n}$ indicates the number of passes in the outer iteration loop. As n_n has zero mean, the impact of noise on the estimates can be reduced by averaging over many values $r_n^C s_n^C$ (large N). However the channel coefficients α_n are time-variant. Thus N has to be determined due to the rate of change of the channel. Of course this rate is related to the user equipment (UE) speed.

Computation of $\hat{\alpha}_{0,n}$ in (4) can be refined by a weighting factor w_i for each sample leading to

$$\hat{\alpha}_{0,n} = \frac{1}{N} \sum_{i=n-N_b}^{n+N_f} w_i r_i^C s_i^C . \tag{5}$$

w_i in (5) allows to weight contributions near to the central element $i = n$ stronger than others. Thus the impact of the time-variance of α_n on the estimate $\hat{\alpha}_{0,n}$ is reduced.

IV. Feedback

The soft output Turbo decoder provides the sequence $x_{0,n}^D$ for the first outer iteration pass. We have investigated different methods how to utilize $x_{0,n}^D$ to improve channel estimation. Various strategies are described in the following.

A. Hard decision and re-encoding

The binary sequence $\hat{b}_{0,n}^D$ with

$$\hat{b}_{0,n}^D = \begin{cases} 1 & : \; x_{0,n}^D \geq 0 \\ -1 & : \; x_{0,n}^D < 0 \end{cases} \tag{6}$$

is fed into a re-encoder that is the same as the encoder at the transmitter side. The output $y_{0,n}^D$ of the interleaver can be considered as a training sequence which is extended by the decoded information bits of the DPDCH. The channel estimator now refines the first estimate $\hat{\alpha}_{0,n}$ by solving

$$\hat{\alpha}_{1,n} = \beta_0 \hat{\alpha}_{0,n} + \frac{\beta_1}{N} \sum_{i=n-N_b}^{n+N_f} w_i r_i^D y_{0,i}^D. \qquad (7)$$

With (2) we get

$$\hat{\alpha}_{1,n} = \beta_0 \hat{\alpha}_{0,n} + \frac{\beta_1}{N} \sum_{i=n-N_b}^{n+N_f} w_i \alpha_i s_i^D y_{0,i}^D + \\ + \frac{\beta_1}{N} \sum_{i=n-N_b}^{n+N_f} w_i n_i y_{0,i}^D \qquad (8)$$

where β_0 and β_1 are scaling factors that we have chosen appropriately. The extended training sequence $y_{0,n}^D$ takes the place of a known pilot pattern.

After the kth outer iteration we obtain according to (7) estimates

$$\hat{\alpha}_{k,n} = \beta_{k-1} \hat{\alpha}_{k-1,n} + \frac{\beta_k}{N} \sum_{i=n-N_b}^{n+N_f} w_i r_i^D y_{k-1,i}^D \qquad (9)$$

The recursive structure of the Turbo re-encoder can cause error propagation which is a drawback of this method.

B. Hard decision and feedback of the information bits only

As the recursive Turbo re-encoder may introduce error propagation, we have considered the following alternative. Only the decoded information bits $\hat{b}_{k-1,n}^D$ of the DPDCH shall be utilized in (9). This can easily be done by adapting the weighting factors w_i:

$$w_i \begin{cases} > 0 & : \ y_{0,i}^D \ \text{is an information bit} \\ = 0 & : \ y_{0,i}^D \ \text{else.} \end{cases} \qquad (10)$$

Additionally, this method reduces complexity, because re-encoding can be skipped.

C. Soft feedback

The performance gain of a receiver with feedback may be degraded by bit errors in the extended training sequence. To overcome this problem reliability information provided by the soft output Turbo decoder can be utilized. $x_{0,n}^D$ are a posteriori L-values of s_n^D conditioned on r_n^D

$$x_{0,n}^D = \ln \frac{P[s_n^D = 1 \mid r_n^D]}{P[s_n^D = -1 \mid r_n^D]} \qquad (11)$$

where $P[\cdot \mid \cdot]$ denotes a posteriori probability. With (11) we can adapt the extended training sequence $y_{0,n}^D$:

$$y_{0,n} = \begin{cases} 2(P[s_n^D = 1 \mid r_n^D] - 0.5): & s_n^D \ \text{is an inf. bit} \\ 0: & \text{else.} \end{cases} \qquad (12)$$

This outer iteration loop is indicated in Figure 2 by a dashed line.

Table 2: Simulation parameters

Information bit rate	64 kbps
DPDCH spreading factor	16
Dedicated pilot bits	6
User equipment (UE) speed	120 km/h
DPCCH-to-DPDCH power ratio γ	variable
Receive antennas	2
Number of pilots N used for CE	18 (3 slots)
Weighting factors w_i	$1 \forall i$
Inner (Turbo decoder) iterations	4
Exit condition	5000 blocks

V. Performance evaluation

Monte Carlo simulations are carried out with a single user link level simulator. Table 2 gives the most important simulation settings. They are valid until otherwise noted.

First, we investigate the impact of the DPCCH-to-DPDCH power ratio γ on the block error ratio (BLER) of the receiver without outer iteration and of the receiver with hard decision and feedback of the information bits (method B). The result is shown in Figure 3. Obviously, the receiver with outer iteration provides a significant performance gain. This receiver benefits from a higher DPDCH power portion than proposed in [3] ($\gamma = -5.46$ dB), because the channel estimation exploits both DPCCH and DPDCH. We find the minimal BLER at about $\gamma = -6.5$ dB for the receiver without outer iteration and at $\gamma = -8.5$ dB for the receiver with outer iteration. As expected, the impact of γ on

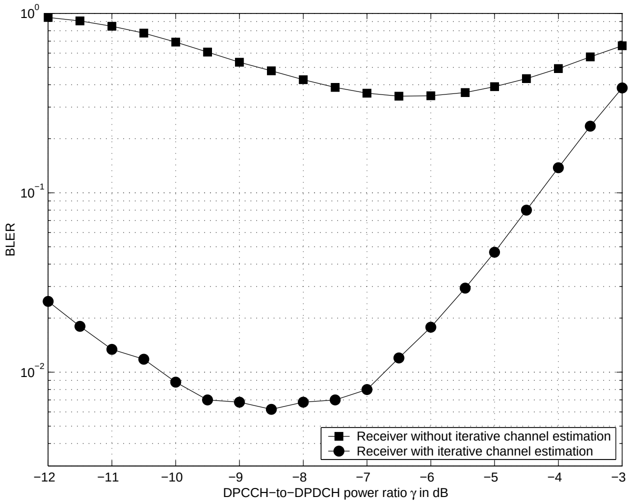

Figure 3: Impact of DPCCH-to-DPDCH power ratio γ on block error ratio (BLER) of receivers with and without iterative channel estimation at $E_b/N_0 = 1.6\,\text{dB}$

BLER is much larger for the iterative channel estimation method compared to the conventional solution.

In Figure 4 the BLER as a function of the signal-to-noise ratio E_b/N_0 is compared for receivers without and with iterative channel estimation (methods A, B and C in section IV). We see, that the channel estimator with outer iteration is superior to the conventional non-iterative method. As the recursive filter in the re-encoder may cause error propagation, the performance gain of method A is only 0.35 dB at a BLER of 1 %. Methods B and C that use hard or soft information bits within the extended training sequence achieve almost the same results. At BLER of 1 % we obtain an improvement of 0.8 dB to the non-iterative channel estimator. The largest gain of 1 dB can be achieved if the optimized DPCCH-to-DPDCH power ratio γ is used.

We have investigated a receiver without iterative channel estimation and a receiver with outer iteration loop and hard decision and feedback of the information bits (method B) for various user equipment (UE) speeds and different DPCCH-to-DPDCH power ratios γ. Figure 5 shows the required E_b/N_0 to achieve a block error ratio (BLER) of 1 %. As can be seen from Figure 5, the receiver with outer iteration loop and optimized DPCCH-to-DPDCH power ratio $\gamma = -8.5\,\text{dB}$ provides the best result over the whole range of speeds. However, the required E_b/N_0 increases with both higher and lower speed. One possible reason for this result is that the channel estimation parameters N and w_i from Table 2 are advantageous for 120 km/h. Additionally, $\gamma = -8.5\,\text{dB}$ was found to be optimal for this speed. These values have been kept constant for all simulations. The receiver without iterative channel estimation and that with outer iteration loop and $\gamma = -5.46\,\text{dB}$ show similar results. Obviously, the performance degradation described above is most clearly pronounced for non-iterative channel estimation and low speed. According to 5, iterative channel estimation can lower the required E_b/N_0 by 1 dB ($\gamma = -5.46\,\text{dB}$) and 1.4 dB ($\gamma = -8.5\,\text{dB}$) for 30 km/h UE speed. For the very high speed of 180 km/h gains are still there, but reduce to 0.6 dB and 0.7 dB, respectively.

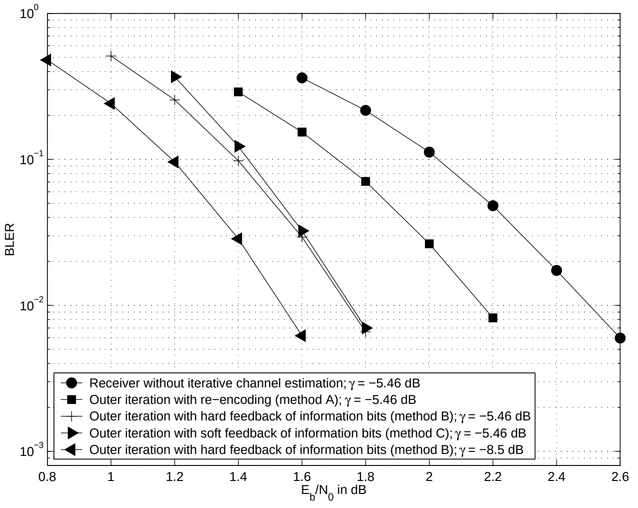

Figure 4: Comparison of receivers with and without iterative channel estimation

Finally, the required number of outer and inner (Turbo decoder) iterations is investigated. We use method B and $\gamma = -5.46\,\text{dB}$. As can be seen from Figure 6 the partitioning of the number of outer and inner iterations has a great impact on the receiver performance.

For the selected examples the best results we obtained for the combinations [1 outer, 7 inner] and [2 outer, 5 inner] iterations. Obviously, the first outer iteration pass provides the highest gain, whereas the following outer iterations give only small additional contribution. As a rule for a given total number of iterations, the largest portion should be dedicated to the inner (Turbo decoder) iteration loop.

VI. Conclusion

Starting from a conventional Node B receiver without iterative channel estimation, we have presented a re-

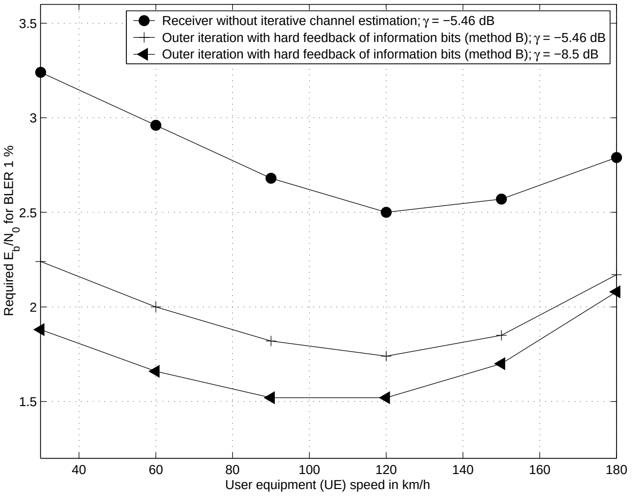

Figure 5: Required E_b/N_0 for block error ratio (BLER) 1 % for varying user equipment (UE) speed

ceiver with feedback from the Turbo decoder output to the channel estimator. This outer iteration loop allows for iterative channel estimation that exploits both DPCCH and DPDCH.

First we have re-encoded the decoded information bit sequence after a hard decision to form an extended training sequence. Monte Carlo simulations have shown, that this method A provides an SNR gain of 0.35 dB compared to the receiver without outer iteration.

The recursive Turbo encoder may cause error propagation. To overcome this problem we have considered an alternative solution. Only the decoded information bits are fed back after hard decision (method B). As a result we have significantly increased the performance to 0.8 dB compared to the conventional receiver. Additionally, complexity is reduced.

As the soft output Turbo decoder provides a posteriori L-values as reliability information for the decoded sequence, we have fed back these L-values without hard decision. We call this method C soft feedback. Simulations have shown that this proposal achieves almost the same results as method B in the SNR regime under consideration.

The DPCCH-to-DPDCH power ratio has a strong impact on the BLER. We have optimized this ratio for receivers with and without iterative channel estimation for UE speed of 120 km/h. It was shown that the optimized DPCCH-to-DPDCH power ratio used in the receiver with outer iteration loop yields a 1.4 dB SNR improvement at low speeds compared to a receiver without iterative channel estimation. For a UE with high speed of 120 km/h we still achieve a significant gain of about 1 dB.

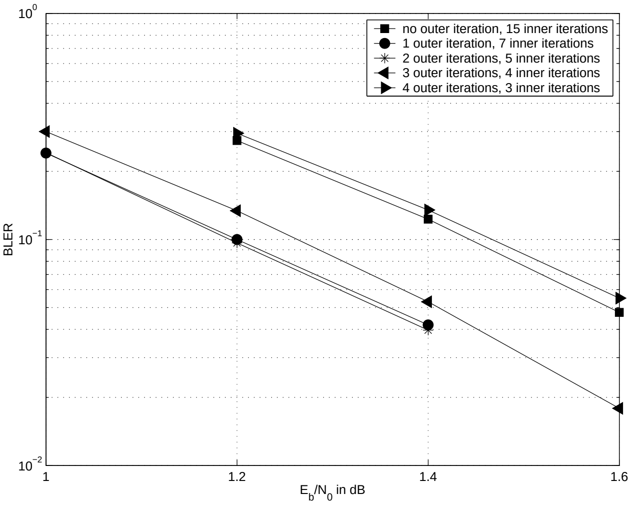

Figure 6: Impact of the number of outer and inner (Turbo decoder) iterations on block error ratio (BLER)

Finally, we have investigated the impact of the number of outer and inner (Turbo decoder) iterations on the BLER. It was found that the first outer iteration pass provides the highest gain. Hence, for a given total number of iterations, the largest portion should be dedicated to the inner iteration loop.

Acknowledgment

For simulations we used an extended version of a Node B link level simulator by M. Jeschke and T. Wild, Alcatel Stuttgart. Some functions of the software were implemented by F. Klingler during his Master Thesis.

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