Correlative Channel Estimation in DS-CDMA Systems

Volker Kühn and Michael Meyer
Department of Communications Engineering
University of Paderborn, 33095 Paderborn, Germany

Abstract: The determination of the propagation conditions of time-variant mobile radio channels is a main task in mobile communication systems. For systems based on CDMA, it is generally assumed that the receiver knows the corresponding spreading sequence. Therefore, this sequence can be used for a correlative channel estimation. This paper considers several concepts for the channel estimation in direct-sequence code division multiple access systems and compares their performances by simulation results.

I. INTRODUCTION

The recent discussion (e.g. [1]) about the a standardization of third generation mobile communication systems shows that systems based on code division multiple access (CDMA) seem to have advantages over conventional systems using time or frequency division multiple access (TDMA respectively FDMA). Particularly, a higher capacity of users is expected [2].

Due to the specific behavior of these systems such as the inherent diversity when transmitting over mobile radio channels and the low spectral density of the data signal, it is necessary to investigate efficient possible realisations.

This paper examines concepts for a correlative channel estimation using code sequences utilized for spreading the data signal. Systems based on the GSM-standard [3] realize the estimation with training sequences occupying a significant part of the transmission. Therefore, the net data rate is reduced. In contrast to this, receivers in a DS-CDMA (*direct-sequence code division multiple access*) system need to know their corresponding spreading codes so that they can be used instead of training sequences [4]. However, there are some effects rendering the estimation. The signals possess a significant lower spectral power density than their GSM counterparts resulting in less accurate estimates due to additive noise.

In the next section the assumed communication system model is presented. Section 3 and 4 describe the correlative channel estimation in DS-CDMA systems and several realization concepts. Finally, simulation results illustrate the performance of these different methods.

II. SYSTEM MODEL

Figure 1 shows the equivalent baseband system model used in this article.

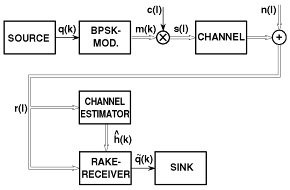

Figure 1: Model of a CDMA-communication system

A binary information source provides an information sequence $q(k)$. This sequence is BPSK-modulated. The symbol duration is denoted by T_s and k indicates the symbol interval. The modulated signal $m(k)$ is spread with a suitable code $c(l)$, where a chip duration T_c is indicated by l. After expanding the bandwidth, the signal $s(l)$ is transmitted over a mobile radio channel with the time-variant impulse response

$$h(l) = \sum_{p=0}^{L} h^{(p)}(l)\delta(l-p), \qquad (1)$$

where $L+1$ propagation paths are taken into account. Furthermore, $h^{(p)}(l)$ denotes the channel coefficient of the p-th propagation path. Additional disturbances are caused by additive white Gaussian noise $n(l)$. The interference of users transmitting at the same time in the same frequency band is treated as white noise according to the Gaussian approximation [5] and is contained in the noise signal $n(l)$.

By using the Rake receiver, the sampled signal $r(l)$ is despread and the signal components delayed by the channel are constructively superposed so that the distortion can be nearly compensated. The quality of this compensation depends on the accuracy of the estimated channel impulse response. Here, it is assumed that the channel estimator provides an estimate once in a symbol interval T_s. Finally, the Rake receiver performs a quantization and feeds the sink with the detected values $\tilde{q}(k)$.

III. CORRELATIVE CHANNEL ESTIMATION

The correlative channel estimation has been successfully applied in GSM-systems for determining the channel impulse response [8], where training sequences known at the receiver are used. A similar procedure is applied to the system discussed in this paper. Principally, DS-CDMA receiver have knowledge of the respective spreading sequence, this can be used for the correlative channel estimation.

First of all, to estimate the time-variant coefficients $h^{(p)}(l)$ of the channel impulse response, the received signal

$$r(l) = \sum_{p=0}^{L} s(l-p) \cdot h^{(p)}(l) + n(l) \tag{2}$$

with

$$s(l-p) = m(l-p) \cdot c(l-p) \tag{3}$$

has to be investigated.

The estimate $\hat{h}^{(i)}(k)$ of the coefficient of the i-th propagation path can be expressed by the correlation of the spreading sequence $c(l)$ and the received signal, with

$$\hat{h}^{(i)}(k) = \frac{1}{G_p} \sum_{l=kG_p+1}^{(k+1)G_p} r(l) \cdot c(l-i). \tag{4}$$

In equation (4) G_p denotes the number of chips per symbol, called the processing gain. Incorporating equation (2) in equation (4) yields

$$\begin{aligned} \hat{h}^{(i)}(k) = \frac{1}{G_p} \sum_{l=kG_p+1}^{(k+1)G_p} \sum_{p=0}^{L} \Big(m(l-p) \\ \cdot c(l-p) \cdot h^{(p)}(l) + n(l) \Big) c(l-i). \end{aligned} \tag{5}$$

By recognizing that the information symbols change only once in a symbol interval T_s and assuming that intersymbol interference can be neglected, it is possible to extract $q(l-p)$ in equation (5) in front of the summation. If the noise term is replaced by $n'(k)$, equation (5) can be expressed as

$$\begin{aligned} \hat{h}^{(i)}(k) &= n'(k) \\ &+ \frac{m(k)}{G_p} \sum_{l=kG_p+1}^{(k+1)G_p} \sum_{p=0}^{L} c(l-p) h^{(p)}(l) c(l-i). \end{aligned} \tag{6}$$

Supposing ideal autocorrelation properties of the spreading codes

$$\frac{1}{G_p} \sum_{l=1}^{G_p} c(l-p) c(l-i) = \begin{cases} 1 & p = i \\ 0 & p \neq i \end{cases}, \tag{7}$$

equation (7) can be simplified as

$$\hat{h}^{(i)}(k) = m(k) h^{(i)}(k) + n'(k), \tag{8}$$

assuming that the channel coefficients remain nearly unchanged during a symbol interval. Equation (7) shows that the channel coefficients can be estimated in each symbol interval if the value $m(k)$ is known and the disturbance caused by $n'(k)$ is sufficiently small. If $m(k)$ is unknown, only the absolute value of the coefficients can be determined because there is an ambiguity in the sign of $\hat{h}^{(i)}(k)$.

IV. CHANNEL ESTIMATION CONCEPTS

A. Overview

In principle, the channel estimation can be performed in different ways, but it is desirable to restrict the net data rate as less as possible.

The results discussed in this paper are based on the following conditions. The data rate is 9.6 kbit/s and the processing gain takes the value G_p=127 so that there is a symbol duration of T_s=104 μs, a chip duration of T_c=0.82 μs, and a bandwith of 1.22 MHz. For spreading m-sequences with a period equal to the symbol duration are applied.

Simulations have been carried out with two channel models, the frequency selective channel *Hilly Terrain* and the model *Rural Area* [9] which does not possess this property. The applied channels are modelled as tapped delay lines and consist of 8 paths in case of *Hilly Terrain* and 2 paths for *Rural Area*. Both channels are simulated with a maximum doppler frequency shift of f_{dmax} = 200 Hz. Due to the maximum delay of $\tau_{max} = 20\mu$s, it seems to be expedient to build up a rake receiver with 26 paths, each of which is delayed with T_c.

Figure 2 illustrates the bit error rates P_b in dependence of the signal-to-noise ratio in the case of exactly known channel coefficients at the receiver. These results can be used for performance classification of the different channel estimation techniques. Furthermore, the theoretical bit error rates of a BPSK-modulated signal transmitted over an AWGN (*Additive White Gaussian Noise*)-channel are shown.

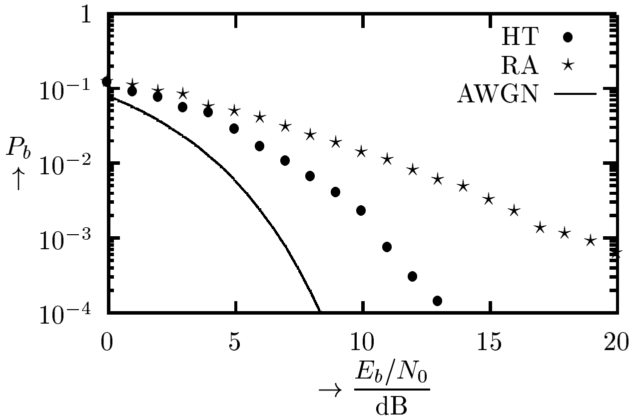

Figure 2: Bit error rates for ideally known channel coefficients for the AWGN-channel and the models *Rural Area* (RA) and *Hilly Terrain* (HT)

The results indicate the advantage of multipath diversity exploited by the rake receiver for the channel model *Hilly Terrain*. For a bit error rate of $P_b = 10^{-3}$ there is only 3.5 dB performance loss compared with the AWGN-channel. In contrast to this, a performance loss of 10.5 dB is achieved in the case of *Rural Area*, where the difference increases for smaller bit error rates. The obvious poorer behaviour of the channel *Rural Area* results from the inferior multipath diversity compared with the model *Hilly Terrain*.

In reality, the channel impulse response is generally not known and has to be estimated. Therefore, two concepts for estimating the channel impulse response are presented. Additionally, a technique which does not depend on the knowledge of the channel state is discussed.

B. Channel Estimation with Training Sequences

In analogy to the GSM system, it is possible to determine the channel impulse response by using training sequences. As shown in Figure 3, training and information sequences, each of which consisting of m symbols, are transmitted alternately. Therefore, the net data rate is reduced.

The channel coefficients are detected during the training phase and are used in the next interval by the Rake receiver for equalizing the data signal. Because the estimated values can be averaged during

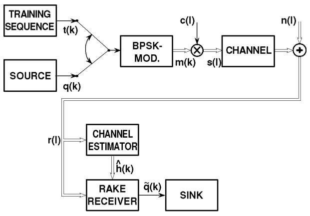

Figure 3: CDMA system with channel estimation based on training sequences

the training interval, their variances can be reduced. If the training phase lasts too long, the bit error rate deteriorates because the channel is time-variant.

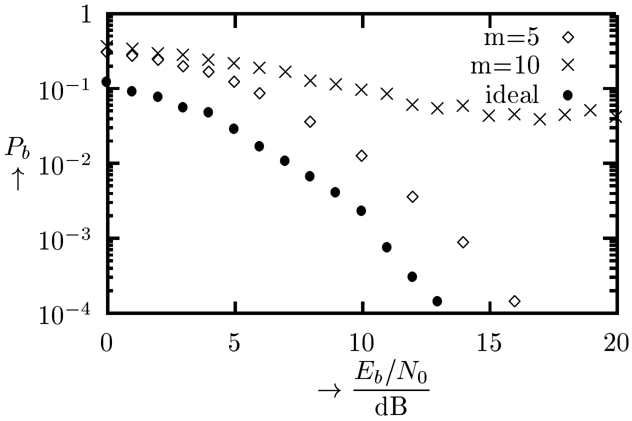

Figure 4: Bit error rates for the channel model *Hilly Terrain* with an impulse response estimated by the use of training sequences

Figure 4 illustrates the good performance of this method for an interval length of m=5. Averaging the calculated channel coefficients during 5 symbol intervals yields accurate estimates so that a performance loss of only 3 dB for a bit error rate of $P_b = 10^{-3}$ is achieved. Due to the high maximum doppler frequency shift of $f_{dmax} = 200Hz$, which is equivalent to a mobile velocity of 240 km/h, the performance decreases if the averaging time is increased to m=10. In this case, the channel coefficients change so quickly that the assumption of nearly constant coefficients during the training phase is violated. Perhaps an iterative adaptation can be used improve the performance.

Similar results for the channel model *Rural Area*

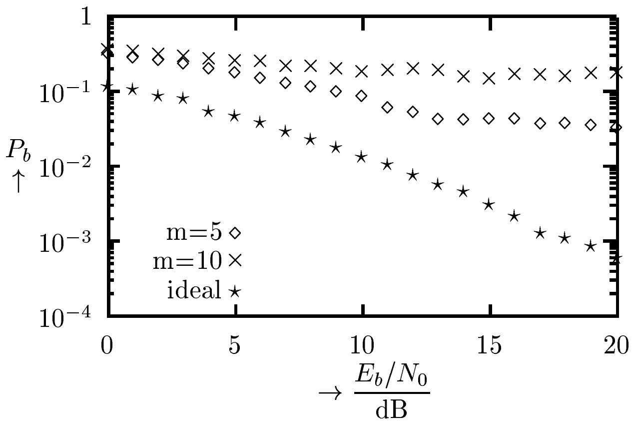

Figure 5: Bit error rates for the channel model *Rural Area* with an impulse response estimated by the use of training sequences

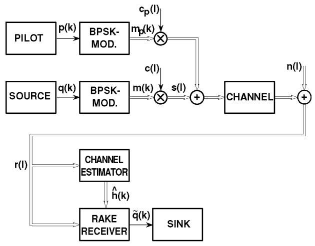

Figure 6: CDMA system with pilot channel assisted channel estimation

are shown in Figure 5. However, the deterioration compared with the case of ideally known coefficients is much more significant.

C. Pilot Channel Assisted Estimation

Concerning the synchronization in CDMA mobile radio systems it seems to be advantageous to use a pilot channel in the downlink [1]. This signal is transmitted with a higher power than the data channels in order to secure the connection between base station and mobiles. Thus, the signal-to-noise ratio is higher compared with data channels. Besides, the propagation conditions are the same for the data signal and the pilot signal so that the latter can be used to determine the channel impulse response. Furthermore, there is no necessity to add more redundancy to the system in order to estimate the channel, because the pilot channel already exists on the downlink.

Figure 6 illustrates the corresponding system model. For simplicity, it is assumed that the pilot channel does not transmit any information, which means the signal is perfectly known by the receiver. Figures 7 and 8 show the received bit error rates for different power ratios g between pilot and data channel for the channel models *Hilly Terrain* and *Rural Area*.

As expected, the inexact knowledge of the channel impulse response yields a performance degradation. Furthermore, the bit error rate decreases for both channel models if the power ratio between pilot channel and data channel is increased. However, it can be recognized that the received performance gain achieved by increasing the pilot signal power diminishes as values of g grows.

Unfortunately, this method cannot be applied in the downlink due to the enormous interferences.

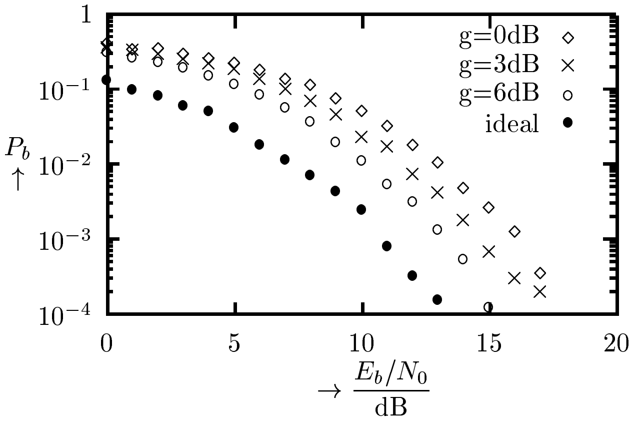

Figure 7: Bit error rates for the model *Hilly Terrain* with pilot channel assisted estimation

Thus, other techniques have to be considered there. Consequently, a third possibility is investigated in the next section.

D. Differential Modulation

The transmission of differential encoded signals makes it possible to avoid the channel estimation as shown in Figure 9. Therefore, it is necessary to assume that the channel impulse response remains nearly unchanged during two consecutive symbol intervals, which is valid for the considered simulation parameters. Here, the transmission of DPSK-modulated signals is investigated. Accordingly, the Rake-receiver has to be replaced by a Rake-receiver for DPSK-signals (s. [7]).

Figures 10 and 11 illustrate the results for both channel models. Additionally, they contain the re-

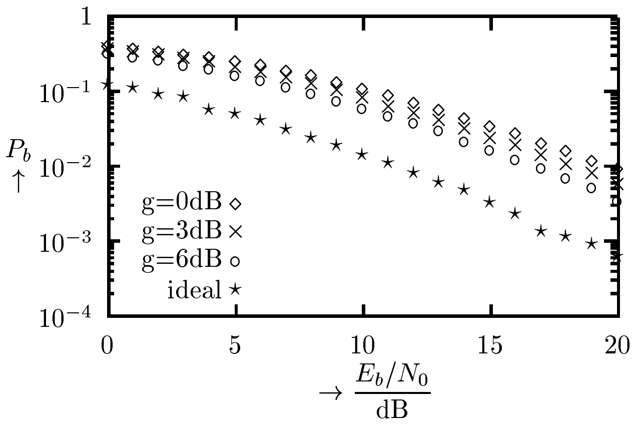

Figure 8: Bit error rates for the channel modell *Rural Area* with pilot channel assisted estimation

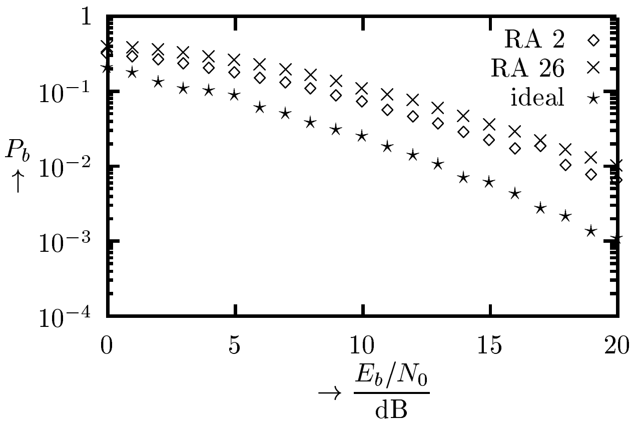

Figure 11: Bit error rates for DPSK-modulation for the channel model *Rural Area* (RA)

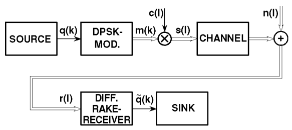

Figure 9: CDMA system with DPSK-modulation

ference curves for ideally known coefficients using a DPSK-modulation. For those systems an approximately doubled bit error rate is achieved compared with the system described in section II, because an error event results in bit errors over two consecutive symbols [7].

The curves indicated by HT 26 and RA 26 show the bit error rate for the full Rake receiver with 26 paths. Additionally, the bit error rates are given for a Rake receiver with the number of paths restricted to the number of paths of the channel (HT 8 and RA 2). The results in Figure 10 and 11 indicate that branches of the Rake receiver having no counterpart in the channel model don't contribute any information and are reducing therefore the signal-to-noise ratio. Thus, the bit error rates for Rake receivers with 26 paths are much worse compared to the cases of HT 8 and RA 2.

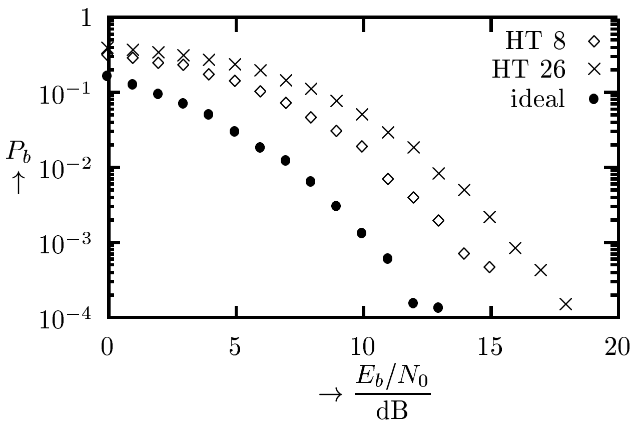

Figure 10: Bit error rates for DPSK-modulation for the channel model *Hilly Terrain* (HT)

V. CONCLUSIONS

This article presents three different methods of determining the channel impulse response in CDMA-systems and compares their performance for a specific system configuration.

Comparing the different concepts, it must be mentioned that the parameter sets are not optimized with regard to a low bit error rate. Therefore, an exact comparison is hardly possible. Nevertheless, differences can be recognized in tendency. The poorest performance is yielded in the system with differential modulation, where the inherent disadvantage of occuring double faults has to be noticed. A major advantage of this technique is the low realization effort compared with the other methods.

The use of a pilot channel seems to provide the best performance. However, this techniques is only practicable in the downlink. Training sequences also represent a possible concept but they reduce the net data rate.

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