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Pilot-aided Adaptive Chip Equalizer Receiver for Interference Suppression in DS-CDMA Forward Link

Frederik Petré[‡] Marc Moonen[§] Marc Engels Bert Gyselinckx Hugo De Man[¶]

Interuniversity Micro Electronics Center (IMEC). Kapeldreef 75, B-3001 Leuven - Belgium

tel. +32-16-281406 fax. +32-16-281515 e-mail : petre@imec.be

Introduction and previous work. In the forward link of cellular and LEO satellite DS-CDMA systems, the different users are multiplexed synchronously to the transmission channel by using orthogonal spreading codes. However, multipath propagation destroys the orthogonality between the different user signals, which causes multiuser interference (MUI). Moreover, power control in the forward link enhances the MUI and creates a near/far problem. The performance of the RAKE, which is the optimum receiver for single-user multipath channels, is severely limited by the MUI.

Multiuser detection techniques [1], that use joint code, timing and channel information, alleviate the near/far problem and offer significant performance improvement compared to the RAKE. Although these techniques are suited to implement reverse link receivers in the base station or the regenerative satellite, they can not be used in the mobile user terminal due to processing power constraints and the need for multiuser a-priori information. Therefore, data-aided and blind linear receiver techniques, based on single-user a-priori information, have been considered for application to the mobile user terminal [2, 3, 4]. These receiver algorithms converge to the MMSE solution but require wide sense cyclostationarity at the symbol rate. Unfortunately, this excludes their application to systems employing aperiodic overlay scrambling codes, since symbol rate cyclostationarity no longer exists in these systems.

In the CDMA forward link, MUI is essentially caused by the channel, since all signals of the code division multiplex are distorted by the same multipath channel when propagating to the user of interest. Therefore, the orthogonality of the user codes can be restored and the MUI can be suppressed by employing channel equalization [5]. Optimal (non-adaptive) zero-forcing (ZF) and MMSE chip equalizer receivers have been introduced in [6] and [7]. They consist of a linear equalizer mitigating the interchip interference, followed by a descrambler/despreader and a decision device. However, adaptive implementations of the chip equalizer receiver, that can deal with fast fading channels, are not straightforward, since no continuous training chip sequence is available. Therefore, current proposals use blind algorithms to update the equalizer coefficients. The blind adaptive equalizer in [8] is based on a constrained minimum output energy criterion. Since this algorithm assumes the knowledge of all spreading codes that are *not* used in the forward link transmission, it will experience severe convergence problems for high system load. The adaptive algorithm proposed in [9], referred to as Griffith's algorithm, is a simple modification of the LMS algorithm. It does not require any training sequence but it does require channel estimation, which can be based on either dedicated pilot symbols or a pilot channel. However, for fast fading channels the estimated channel will lag behind the actual channel and performance will degrade accordingly. Therefore, a direct adaptive implementation, that does not require explicit channel estimation, is more suited for fast fading channels.

Pilot-aided adaptive chip equalizer receiver. We propose a new pilot-aided direct adaptive chip equalizer receiver, that is continuously updated at the symbol rate and therefore is well-suited for fast fading multipath channels. The proposed receiver exploits the presence of a pilot channel in forthcoming third generation mobile cellular and satellite communication systems [10]. It consists of two parts : an updating part and the actual detection part.

The updating part employs the pilot channel to adaptively update the equalizer coefficients. Indeed, by reversing the order of the chip equalizer and the descrambler/despreader, one obtains an elegant adaptive scheme operating at the symbol rate. For a particular symbol the descrambler/despreader provides $2F + 1$ correlation values, with F the order of the FIR channel. These values are the correlator outputs at the correct symbol instant and F chip periods before and after the correct symbol instant. The equalizer (with $2F + 1$ coefficients) coherently combines these correlation values to obtain an estimate of the transmitted pilot symbol. The optimal equalizer coefficients are determined iteratively by using a simple LMS scheme or a more advanced RLS scheme [11].

The detection part operates like the conventional chip equalizer receiver. Initially, it uses for each symbol instant the corresponding equalizer coefficients to equalize the received signal. Finally, it descrambles and despreads the equalized signal and makes a decision about the transmitted data symbol. Note that the equalized signal is common to all codes that have been assigned to the mobile user terminal in a multi-code system, so a single equalizer suffices.

Simulation results. We consider a DS-CDMA forward link signal with K active, equal power users, BPSK data modulation, real orthogonal Walsh-Hadamard codes of length $N = 32$ along with a Gold overlay code for scrambling. The bit

[‡] PhD student at KULeuven, E.E. Dept., supported by an I.W.T.-scholarship

[§] Research Associate F.W.O., KULeuven, E.E. Dept., ESAT/SISTA

[¶] Senior Research Fellow of IMEC, Professor at KULeuven, E.E. Dept.

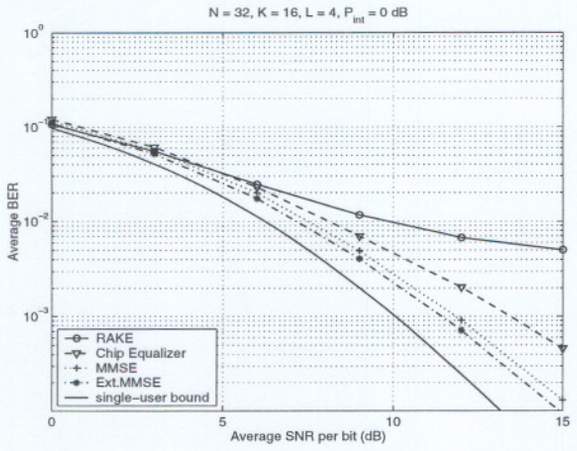


Figure 1: Half system load

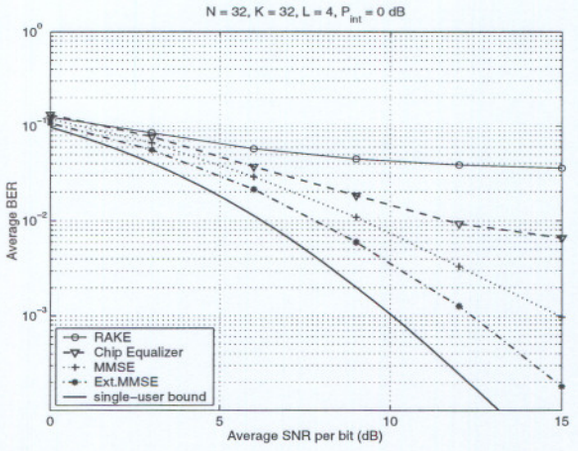


Figure 2: Full system load

error rate (BER) performance of the pilot-aided RLS adaptive chip equalizer receiver, with $F = 3$, is compared to those of the RAKE receiver and both the conventional (observation interval of one symbol period) and the extended (observation interval of three symbol periods) MMSE receiver [4] in a time-varying Rayleigh fading channel with $L = 4$ resolvable paths of equal average power. Note that both the conventional and extended MMSE receiver require a short overlay code in order to assure symbol rate cyclostationarity. Figure 1 shows the BER performance of the different receivers for half system load ($K = 16$) while figure 2 does the same for full system load ($K = 32$). Also shown on the figures is the theoretical BER-curve of BPSK with Lth order diversity in Rayleigh fading channels (single-user bound) [12]. The performance of the RAKE exhibits an error floor due to the MUI. The adaptive chip equalizer offers considerable gain compared to the RAKE, especially under heavily loaded conditions. Both MMSE receivers outperform the chip equalizer because they explicitly detect the data symbol of the desired user. The extended MMSE receiver outperforms the conventional one, since it coherently combines *all* useful signal energy (assuming the delay spread is limited to one symbol period) while the conventional one only combines the useful signal energy on the desired symbol interval.

Conclusions. We have proposed a new pilot-aided direct adaptive receiver structure for the forward link of DS-CDMA systems employing aperiodic overlay scrambling codes and operating in a fast fading multipath environment. By equalizing the multipath channel effects, the receiver restores the orthogonality between the different users and therefore suppresses the MUI. An LMS or RLS symbol rate adaptation scheme, well-suited for fast fading channels, has been obtained by simply reversing the order of the equalizer and the descrambler/despreader for the updating part. Simulation results show that the proposed receiver outperforms the conventional RAKE receiver, especially for heavily loaded systems.

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