REDUCED DIMENSION RECEIVER CONCEPTS IN THE WCDMA UPLINK

Wolfgang Utschick and Frank Dietrich

Institute for Circuit Theory and Signal Processing, Munich University of Technology, 80290 Munich, Germany
Phone/Fax: +49-89-289-28524 / -28504, E-mail: utschick, dietrich@ei.tum.de

1. INTRODUCTION

High spectral efficiency is one of the key factors for an economically successful deployment of WCDMA in the 3rd generation of mobile communication systems. It is the measure for the capability of a system to serve a large number of users with a certain quality of service using a fixed bandwidth. There is a strong interest of the industry to develop powerful signal processing and coding schemes, which increase overall system capacity. Systems with smart antennas are one of the most promising approaches to combat fading, reduce multiple access interference, decrease intercell interference, and therefore achieve a higher capacity. With respect to system capacity uplink and downlink can be treated independently in WCDMA, as it operates in frequency division duplex mode. Principally, smart antennas are adaptive and powerful signal processing. In this article receiver concepts for the WCDMA uplink are presented.

So far linear and nonlinear techniques have been developed separately. Linear receivers are usually less complex, whereas nonlinear techniques show better performance. Maximum likelihood (ML) techniques are generally nonlinear and can achieve the Cramér-Rao lower bound. We use linear receiver concepts [1] in a preprocessing step to reduce the dimensionality of the channel, focus on the subspaces of interest and combine them with a suboptimal maximum likelihood based receiver, called "spatial diversity scheme with interference cancellation" (SD/IC), from Dahlhaus et al. [2]. Thereby we decrease complexity considerably with equal performance at low SNR and a small loss in performance at high SNR.

2. SIGNAL AND CHANNEL MODEL

WCDMA has two channels, the dedicated physical control channel (DPCCH) and the dedicated physical data channel (DPDCH). We consider a connection with one DPCCH and one DPDCH, which are code and IQ multiplexed on the uplink. Both channels use BPSK modulation and are spread with different spreading factors, mapped to the I and Q branches, scrambled with a long complex scrambling sequence and finally transmitted. The chip rate is $1/T_c = 4.096$ Mchips/s, but was changed recently. [1] The fading channel be frequency selective.
For now we consider the single user case with interference modeled as spatially and temporally white Gaussian noise.

3. REDUCED DIMENSION RECEIVERS

3.1. Reduced order SD/IC

A general ML receiver performs channel estimation and symbol detection jointly. The resulting complexity of the required multidimensional optimization on a continuous complex space in the channel parameters and discrete space in the symbols is not feasible. The SD/IC scheme [2] performs channel estimation using the space-alternating generalized expectation-maximization (SAGE) algorithm, a ML technique, independently from symbol detection. For symbol detection a multistage detector is used, which can be derived from general ML detection under certain assumptions [3]. Moreover, there is the possibility to iterate between channel estimation and detection to approach the optimal solution. We perform one iteration, as it turned out

[1] The new chiprate has no impact on the performance of signal processing algorithms and was decreased to facilitate inexpensive receiver hardware.

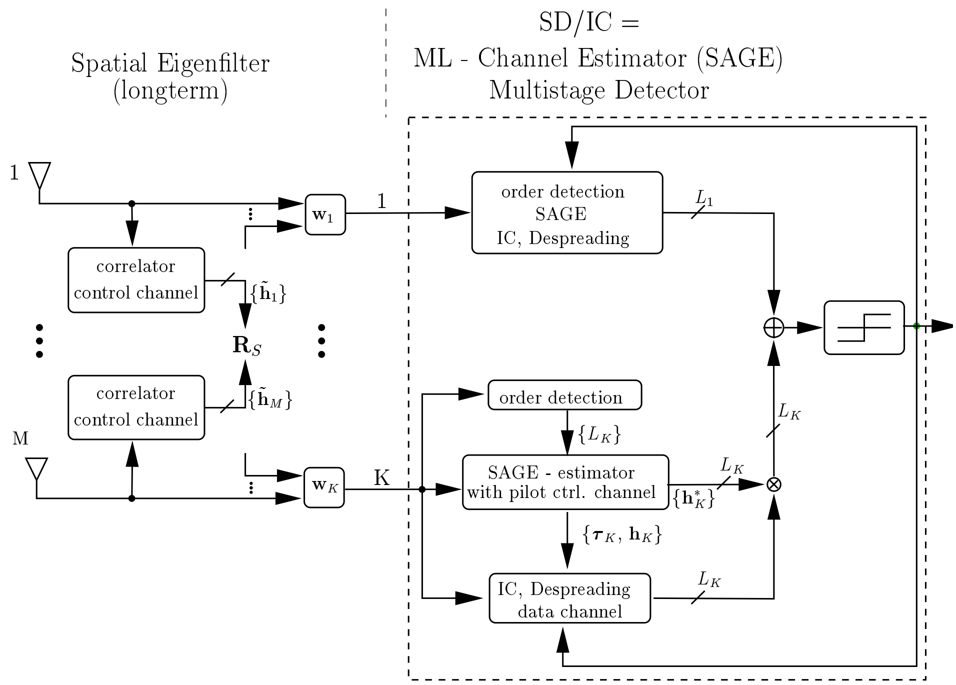

Figure 1: Structure of reduced order spatial diversity scheme with interference cancellation (SD/IC).

that the interference of the data channel, which is not known to the receiver in the first iteration, on the channel estimation is small for the chosen set of parameters. The full approach SD/IC is shown in the second stage of Figure 1.

Originally SD/IC was designed as a diversity technique. If an antenna array of M antennas is used, the spatial correlation of the receive signal at the elements can be exploited. This is done in a first step by a spatial eigenfilter. In the case of white interference it comes down to choosing the eigenvectors corresponding to the K dominant eigenvalues of the spatial signal covariance matrix (a method also known as principal component analysis or Karhunen-Loève expansion). The eigenvalues correspond to the signal plus noise power. Using the eigenvectors as spatial filters we obtain K uncorrelated signals. If we choose the dominant eigenvectors, we restrict further processing to the signal subspace with high SNR relative to the SNR at the antenna. As the spatial characteristic of the channel changes slowly, the covariance matrix can be estimated over several slots with high accuracy. An exponential forgetting factor is employed in a time-variant scenario.

The amount of signal power neglected depends on the scenario and is typically small in the single user case, even in a picocellular scenario. We reduce the spatial dimensionality of the channel from M to K and reduce complexity of the detection step. Most importantly the quality of channel estimation, which is considered one of the burdens on the way to higher system capacity, is improved due to a better SNR after spatial filtering.

3.2. From SD/IC to ST eigenrake

Next we extend linear preprocessing in order to reduce the channel further. SD/IC is based on a diversity channel model, i.e. angle of arrival is not used explicitly and the channel order is given by the number of temporal taps L. We estimate the spatial covariance matrix for each tap separately using the pilot sequence in the DPCCH and choose the K dominant eigenvectors among the eigenvectors from all covariance matrices.

If the wavefronts from different taps arrive from separable directions, the order of the channel at every output of the spatial filters is one. In this case the multistage detector reduces to a maximum ratio combiner and the SAGE channel estimation resumes a correlator (Figure 2). This is the well known space-time (ST) eigenrake [4], which can now be viewed as a suboptimal ML receiver in the case of full order reduction, a single user scenario, and one iteration. In the original implementation of the space-time eigenrake a Wiener filter is used instead of the maximum ratio combiner (MRC) to prevent degradation in performance, if there is a model order mismatch, i.e. the number of taps at the output of every spatial filter is larger than one (intersymbol interference).

4. RESULTS

Simulation results with 320 slots for a picocellular scenario are shown in Figure 3. The channel is generated as described in [5]. The spreading factor in the DPCCH is 256 and 8 in the DPDCH to reduce simulation time and interference from data channel on the quality of channel estimation. The SNR is defined as the total received signal power over the noise power. K is the number of fingers or spatial filters used in the ST eigenrake, which is full order reduction and SD/IC.
Our complexity is measured in number of flops, i.e. a complex addition equals 2 flops, a complex multiplication 6 flops. Note, that the complexity of the ST eigenrake is independent of the SNR (Table 1), as no estimation of the channel order is performed counting the number of significant correlation coefficients. Considering complexity and performance of the algorithms, we conclude that the ST eigenrake (K=4) performs significantly better than the reduced order SD/IC (K=1) having the same complexity. Reducing the order of the full approach SD/IC to K=2, we have a small loss in performance at high SNR, but save 50 % computational effort. Generally it can be seen from Figure 3, that there is only a small difference in BER at low SNR between all algorithms due to the increased SNR after spatial filtering. A reduction in dimension results in an improved robustness in channel estimation.
In a rural scenario with waves arriving from one direction and a delay spread of 4 taps, full performance is already achieved with reduced order SD/IC and K=1 (Figure 4). As all taps arrive from one main direction, the ST eigenrake with MRC suffers from model order mismatch, i.e. intersymbol-interference. A Wiener filter instead of MRC, which is the algorithm proposed in [4], suppresses interference and performance is improved at high SNR (Figure 4).

5. CONCLUSIONS

Linear preprocessing based on the longterm estimate of spatial covariance matrices reduces receiver complexity by 50% with only small loss in performance. Interpreting linear preprocessing as model order reduction, the ST eigenrake can be seen as a maximum likelihood receiver operating on the reduced channel. Further results and more details about low-rank techniques can be found in [6, 7].

6. REFERENCES

[1] C. Brunner, *Efficient Space-Time Processing Schemes for WCDMA*. Ph. D. dissertation, Technical University of Munich, Institute of Network Theory and Signal Processing, Germany, 2000. Shaker Verlag, ISBN 3-8265-8062-1.

[2] D. Dahlhaus, A. Jarosch, and Z. Cheng, "Smart antenna concepts for the UMTS terrestrial radio access," in *Proceedings of Smart Antennas Workshop at the European Microwave Week*, 6 October 1999.

[3] M. K. Varanasi and B. Aazhang, "Multistage Detection in Asynchronous Code-Division Multiple-Access Communications," *IEEE Trans. on Communications*, vol. 38, pp. 509–519, April 1990.

[4] C. Brunner, J. S. Hammerschmidt, A. Seeger, and J. A. Nossek, "Space-time eigenrake and downlink eigenbeamformer: Exploiting long-term and short-term channel properties in WCDMA," in *Proceedings of IEEE GLOBECOM*, November 2000.

[5] J. J. Blanz and P. Jung, "A flexibly configurable spatial model for mobile radio systems," *IEEE Trans. on Communications*, vol. 46, pp. 367–371, Mar. 1998.

[6] W. Utschick and J. Nossek, "Low-rank signal processing in wireless communications." Submitted to IEICE Transactions on Communications, 2001.

[7] C. Brunner, W. Utschick, and J. Nossek, "Exploiting the short-term and long-term channel properties in space and time: Eigenbeamforming concepts for the BS in WCDMA." Submitted to European Transactions on Telecommunications, 2001.

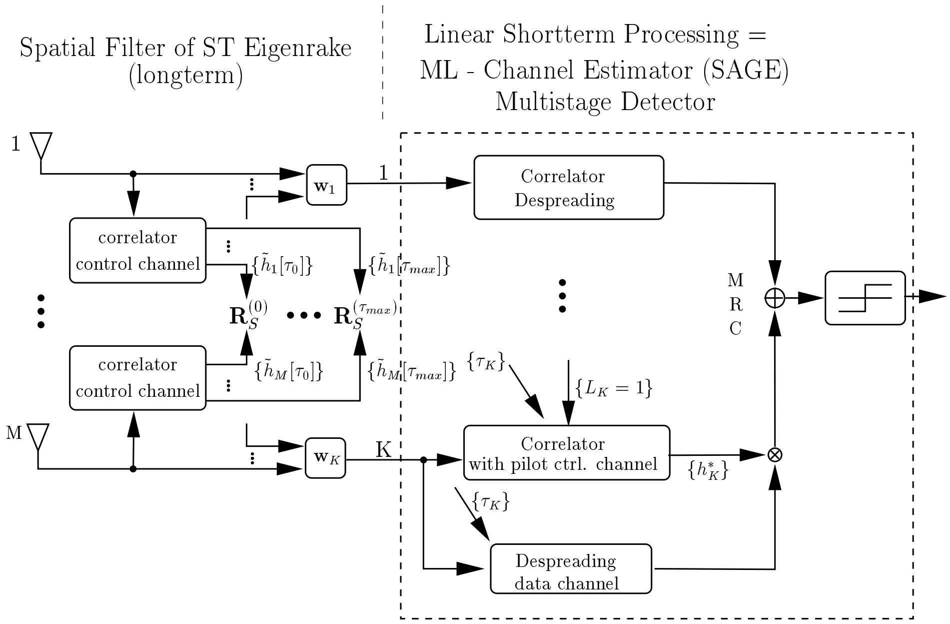

Figure 2: Structure of spatial diversity scheme with interference cancellation (SD/IC) with full order reduction, which is equivalent to space-time (ST) eigenrake.

SNR in dB	-6	-3	0	3	6	9	12	15
Full SD/IC	76.45	75.98	75.68	75.02	74.68	74.50	74.48	74.54
Reduced SD/IC, K=2	38.44	38.00	37.75	37.44	37.29	37.15	37.20	37.22
Reduced SD/IC, K=1	19.52	19.34	19.41	19.33	19.40	19.44	19.42	19.41
ST eigenrake, K=4	20.72	20.72	20.72	20.72	20.72	20.72	20.72	20.72

Table 1: Complexity in millions of (real) flops per slot of full approach SD/IC, reduced order SD/IC and ST eigenrake.

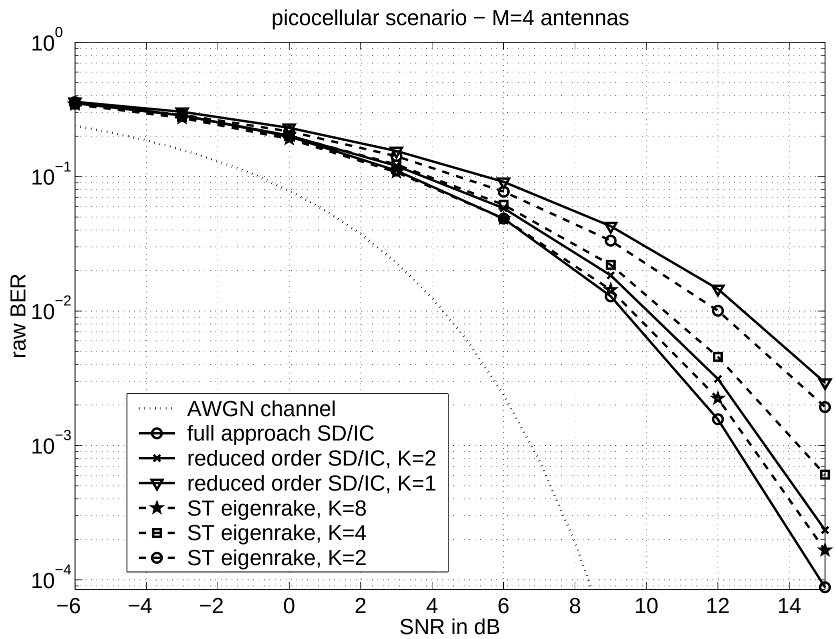

Figure 3: Raw bit error rate of full approach SD/IC, reduced order SD/IC and ST eigenrake in a picocellular scenario (Simulation parameters: uniform linear array, 4 antennas, spacing: $\lambda/2$, 320 slots = 200 ms, speed: 15 km/h).

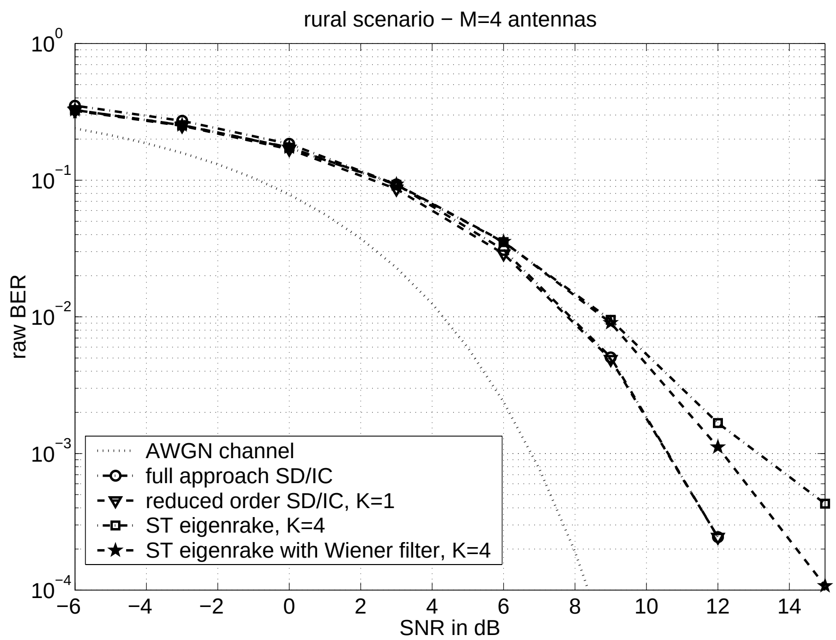

Figure 4: Raw bit error rate of full approach SD/IC, reduced order SD/IC and ST eigenrake in a rural scenario (Simulation parameters: uniform linear array, 4 antennas, spacing: $\lambda/2$, 320 slots = 200 ms, speed: 100 km/h).