Fixed Point DSP Implementation of Iterative Multi-User Detection with Channel Estimation for UMTS

K.Wacker, W. W. Ng, P. B. Darwood, P. D. Alexander, I. Oppermann
Southern Poro Communications (SPC)
Level 2, 6A Nelson Street, Annandale
NSW 2038, AUSTRALIA
{klausw, woonn, peterd, paula, iano}@southern-poro.com

1. Abstract

This document gives a brief description of a UMTS WCDMA iterative multi-user receiver previously presented in [1],[2] using various modulation schemes. The main advantage is the great increase in spectral efficiency in both up-link and down-link environments with mixed data rate users. The paper focuses on higher order modulation as well as on the performance of mixed data rate scenarios. Results are presented in the form of "water fall" diagrams. The implementation is completely based on 16-bit fixed-point and proves to be very accurate with only slight performance degradation compared to "infinite precision" floating-point implementation.

2. CDMA System Model

The CDMA multipath channel model is shown in *Fig. 1*. The input to the channel is a discrete signal consisting of K users. The k^{th} users' information sequence b_k is coded by a rate R encoder resulting in a sequence d_k.. After interleaving the information is modulated. The random spreading sequences are used, but similar performance can be reported for UMTS spreading and scrambling codes. The multipath channel is modelled as an FIR filter with M multipath taps $\boldsymbol{h}_k$, each tap has a discrete block invariant delay and a complex amplitude. The amplitude estimation is included in the receiver structure. All users are combined to one signal with complex Gaussian noise of variance $\sigma^2 = \frac{1}{2} N_0$.

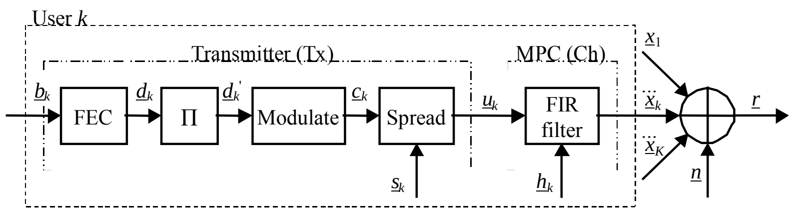

Fig. 1. CMDA multi-path model.

3. Iterative CDMA Receiver Structure

The "turbo-code" based mechanism passes soft estimates between single-user FEC and a multi-user detector, which in this structure consists of a parallel interference canceller (PIC) and a correlator.

Mapping for BPSK and QPSK type modulation is trivial, however mapping for higher order modulation requires the knowledge of the noise variance, because soft-demodulation is required [3].

After the de-interleaver reorders the d_k, the FEC decoder can extract the estimated information bits out of d_k. The FEC is supplied with a-posteriori probabilities. Symbol noise variance is a requirement for reliable results although overestimating of the noise variance is preferable to underestimating.

The FEC extracts information bits as well as it produces estimates of d_k, which are fed back into the following interleaver and re-mapper. The resulting signal c_k is an estimate of the signal each user sent.

Channel estimation is an integral part of the receiver, which represents a significant improvement of this architecture over other structures. Channel taps are calculated with the help of a training sequence. The results are produced with a 10% portion of training symbols. Any training sequence may also be used for variance estimation.

4. Implementation Issues

The implementation in a fixed-point environment inherently degrades the precision and limits the range of values. Therefore normalisation functions and overflow checking must be applied to every part of the receiver.

Another implementational issue is the lack of several basic mathematical functions in hardware i.e. division or exponential function. Typically, many more cycles are required to calculate a division or a square root than for a

single cycle multiplication. Also tables are designed in such a way that divisions can be replaced by shifts.
Instead of exact values only the relative ratio between state probabilities are needed in a MAP decoder, which saves numerous operations. This comes with the cost of precision and degradation in over all performance.

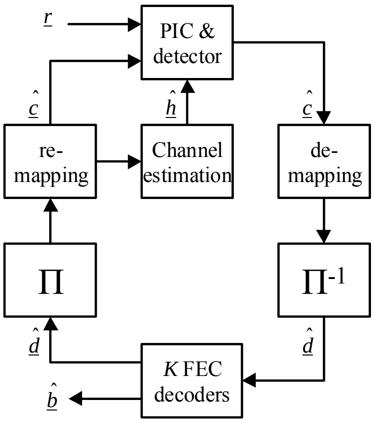

Fig. 2. System diagram of iterative multi-user CDMA receiver.

5. DSP Results

The packet length is fixed at 2560 chips, with a time-division duplex training portion of 10% of the total packet length. The multi-path channel is chosen to have 3 complex taps of unknown amplitude and phase, with delay spread ranging from 1 chip to a maximum of 1 symbol length. The channel multi-path component delays are assumed known at the receiver, however in practise these can be estimated with a sliding correlator. The forward error correction is provided by a simple ½ rate 4 state maximum free distance convolutional code (d_{free}=5) with *a-posteriori* probability (soft) decoding.

5.1 Performance with mixed data rates and QPSK

UMTS allows users to vary data rate by selecting different spreading ratios. All spreading ratios may be used together. *Fig. 3* shows the performance of an up-link (asynchronous) mixed data rate system, 1 user N=4, 2 users N=8, 8 users N=16. The channel delay-spread ranges from 1 chip to 1 symbol. The user signals are band limited using a pulse-shaping filter.
Fig.4, Fig.5 and *Fig.6* display the performance of QPSK with two out of the three (N=4, N=8, N=16) possible spreading ratios. Each simulation's load is added up to 100% and each user group uses 50 % of the load.

5.2 Performance with Higher Order Modulations

Fig.7 and *Fig.8* demonstrate the performance of the iterative multi-user receiver with 8-PSK and 16-QAM modulation,

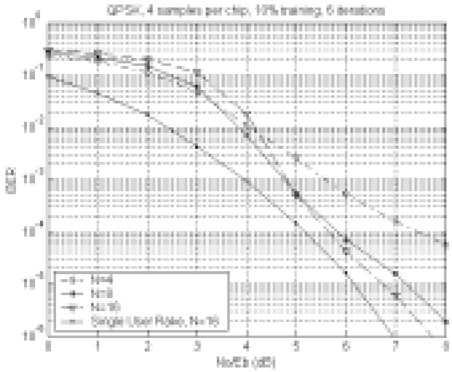

Fig. 3. QPSK with variant spreading length

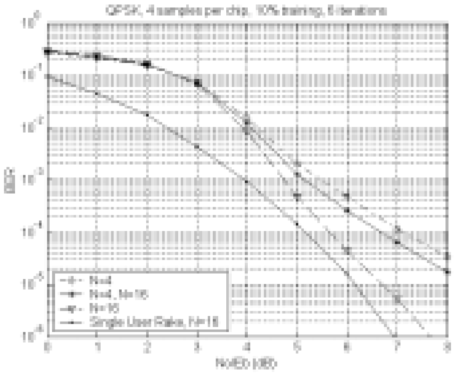

Fig. 4. QPSK with spreading length N=4, N=16

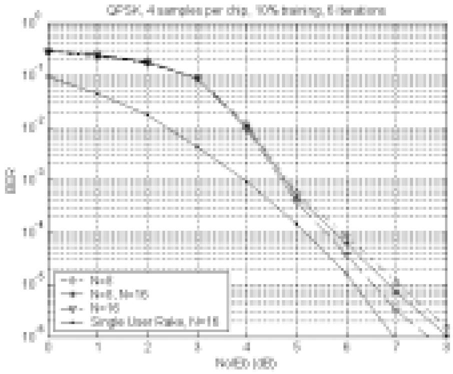

Fig. 5. QPSK with spreading length N=8, N=16

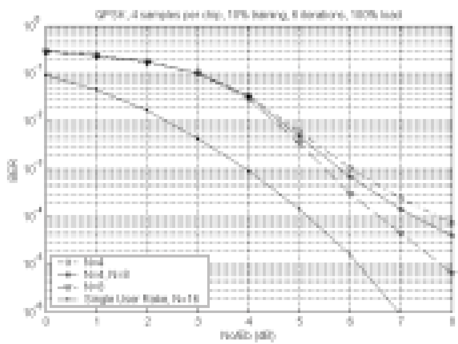

Fig. 6. QPSK with spreading length N=4, N=8

with respective loads of 75% and 50%. It can be observed that at these loads, the receiver requires about 6 to 7 iterations to converge. Using 8-PSK modulation, it is noted that the receiver approaches (within 0.3dB) the performance of a single-user RAKE receiver over the same multi-path interference channel. It should also be noted that the performance of a linear correlator receiver with the same load and multi-path interference channel is equivalent to the performance of the *first* iteration of the non-linear iterative multi-user receiver presented.

Fig. 9 presents the results for BPSK modulation in terms of BER against SNR and load, β. It can be noted that the number of BPSK users supported is well above 200%.

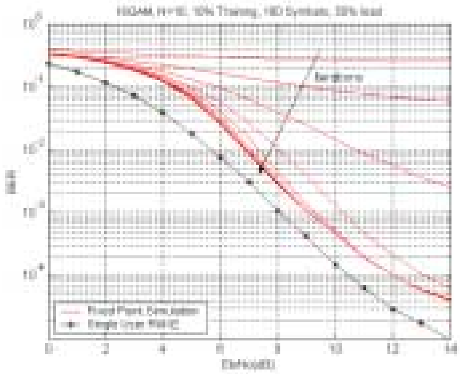

Fig.7. BER Performance 16-QAM

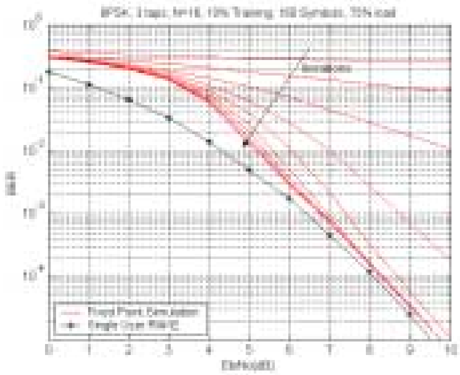

Fig. 8. BER Performance 8-PSK

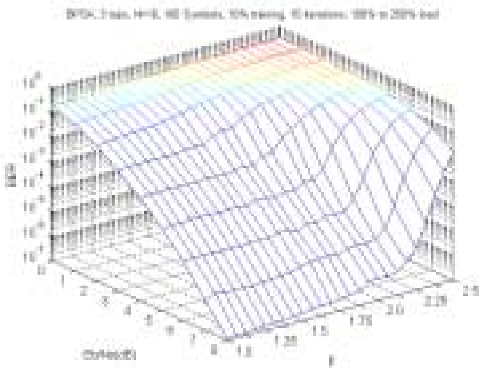

Fig. 9. BPSK BER Performance against SNR and load

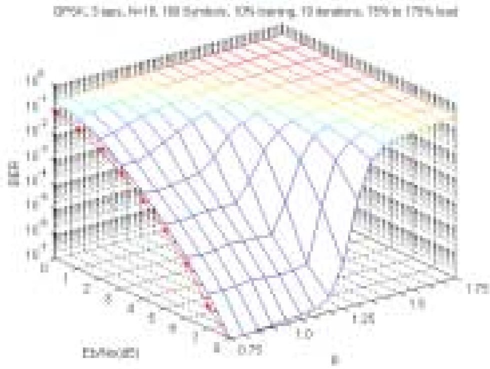

Fig. 10. QPSK BER Performance against SNR and load

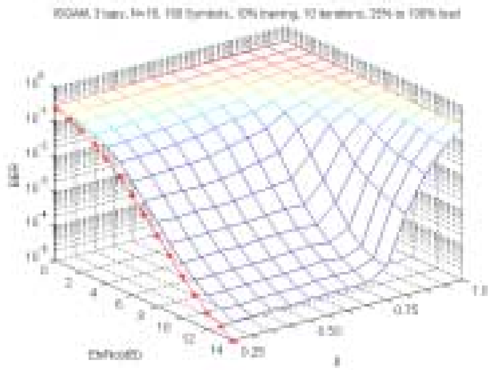

Fig. 11. 16QAM BER Performance against SNR and load

For QPSK modulation as shown in *Fig. 10* the number of users supported is above 100% (β>1.0), as well as shown in *Fig. 11* the possible load for 16QAM is above 75% (β>0.75).

6. Conclusions

The DSP generated results presented in this paper show that the receiver is capable of supporting a large number of users, relative to the spreading gain, and thus achieves excellent spectral efficiency. Furthermore, the fixed-point implementations of the receiver indicate that mapping the receiver design to VHDL is achievable. To increase performance it would be suitable to build a multi processor system, where each DSP processes the data of one user and a central processor handles the parallel interference cancellation.

References

[1] P. D. Alexander and A. J. Grant, “Iterative decoding and channel estimation”, *IEEE ISIT’2000*, p. 171, June 2000.

[2] A. J. Grant and P. D. Alexander, “Convergence analysis for iterative multi-user decoding”, *Proc. PIMRC 2000*, pp. 519-523, Sept. 2000.

[3] P.B. Darwood, P.D. Alexander, K. Wacker, I.J. Oppermann ”Iterative Multi-User Detection and Channel Estimation for CDMA with non- Binary Modulation”, *to appear in Globecom Nov 2001*.