MMSE ADAPTIVE RECEIVER FOR UTRA TDD

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ABSTRACT

A modified implementation of the MMSE receiver to be used in a UTRA TDD environment is presented. Simulations are carried out in a multipath fading environment and BER values are obtained, demonstrating that this structure reduces the MAI that appears due to the loss of orthogonality between orthogonal codes in multipath channels. The performance of the proposed structure is compared with that of a traditional receiver, an equaliser and a RAKE receiver.

1. INTRODUCTION

In additive white Gaussian noise (AWGN) channels there is no multiple access interference (MAI) [1] if orthogonal spreading codes are used in a synchronous CDMA system. However, orthogonality is lost due to multipath and MAI suppression techniques have to be used in order to increase the capacity of the system. These techniques are easily applied when short spreading codes are used.

The proposed UTRA time division duplex (TDD) [2] mode makes use of two spreading codes [3]. In this paper we present a modification of the minimum mean squared error (MMSE) receiver that can operate in a TDD environment. First the basic concepts of UTRA TDD and the traditional MMSE receiver are presented. Next the modified MMSE structure is introduced and tested in a TDD environment using multipath fading channels. Its performance in terms of bit error rate (BER) is compared to that of other receiver structures, namely, traditional receiver, linear equaliser followed by a traditional receiver and RAKE receiver.

2. TDD FOR UTRA

Duplex communication is provided in TDD by means of time slots which separate uplink and downlink [2]. In addition to this TDMA [4] element, UTRA TDD also introduces a CDMA [1] component, within each time slot users are separated by means of spreading codes.

Two spreading codes are used in UTRA TDD to obtain the spread spectrum signal [3]. Each data symbol d_k is spread using a spreading code $\boldsymbol{c}$ and a scrambling code $\boldsymbol{v}$ which are defined as

$$\boldsymbol{c} = \begin{bmatrix} c_0 \; c_1 \; \dots \; c_{Q-1} \end{bmatrix}^T \qquad (1)$$

$$\boldsymbol{v} = \begin{bmatrix} v_0 \; v_1 \; \dots \; v_{Q_{\mathrm{MAX}}-1} \end{bmatrix}^T \qquad (2)$$

where Q is the spreading factor with possible values $Q = \{1, 2, 3, 4, 8, 16\}$ and Q_{MAX} is the maximum value of the spreading factor. The spreading process of two consecutive symbols b_k and b_{k+1} for $Q = 8$ is shown in Figure 1.

The spreading codes $\boldsymbol{c}$ are orthogonal variable spreading factor (OVSF) codes [5], and the scrambling codes $\boldsymbol{v}$ are specified in [3].

3. MMSE RECEIVER

In an ideal AWGN channel, the cross-correlation of orthogonal codes is zero [5], therefore avoiding multiple access interference (MAI). However, orthogonality is lost when multipath components are present in the channel and the BER in a DS-CDMA system using OVSF codes can be seriously degraded [6]. Nevertheless, a MMSE receiver [7] can be used to minimise the effect of MAI due to the lost of orthogonality in a multipath channel.

The structure of an adaptive MMSE receiver is shown in Figure 2. Assume a multiuser system where the kth bit of the lth user is spread using a short sequence of length N

$$\boldsymbol{s}_l = \begin{bmatrix} s_{0,l} \; s_{1,l} \; \dots \; s_{N-1,l} \end{bmatrix}^T \qquad (3)$$

The transmitted signal can be expressed as $b_{k,l}\boldsymbol{s}_l$, and in a synchronous scenario with L users and an ideal AWGN channel the received signal sampled at the chipped rate R_c is

$$\boldsymbol{r}_k = \sum_{l=0}^{L-1} \sqrt{E_{k,l}}\, b_{k,l}\boldsymbol{s}_l + \boldsymbol{n}_k \qquad (4)$$

where $\sqrt{E_{k,l}}$ is the the energy corresponding to $b_{k,l}$, and $\boldsymbol{n}_k$

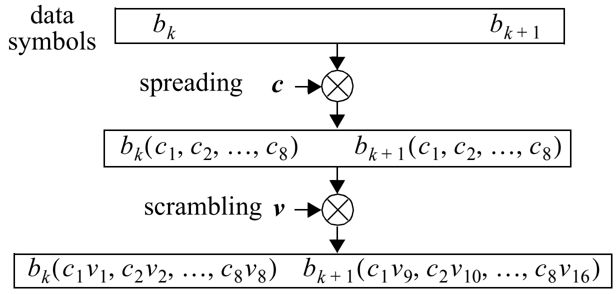

Figure 1: Spreading and scrambling for $Q = 8$

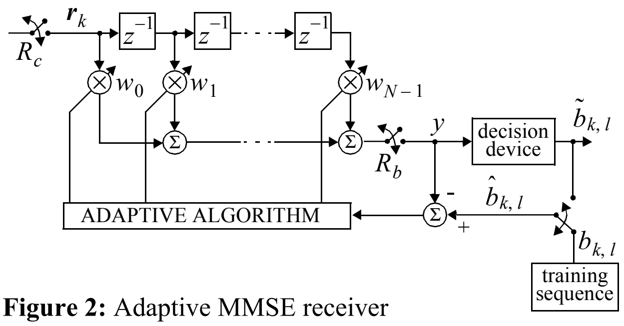

Figure 2: Adaptive MMSE receiver

is the noise samples vector. Eq. 4 is also valid when operating in a multipath environment as the effect of multipath can be introduced in the definition of $\boldsymbol{s}_l$ as shown in [7].

When the filter tapped delay line has been loaded with the N samples corresponding to $b_{k,l}$, the output of the adaptive filter y can be calculated at the bit rate R_b as $y = \boldsymbol{w}^T\boldsymbol{r}_k$, where $\boldsymbol{w}$ is the filter weights vector

$$\boldsymbol{w} = \begin{bmatrix} w_0 \; w_1 \; \dots \; w_{N-1} \end{bmatrix}^T \tag{5}$$

which is chosen to minimise for the user of interest the mean squared error (MSE)

$$\xi_{k,l} = \{(\boldsymbol{w}^T\boldsymbol{r}_k - \hat{b}_{k,l})^2\} \tag{6}$$

this minimisation process can be performed adaptively by means of an adaptive algorithm [8]. $\hat{b}_{k,l}$ takes the value of $b_{k,l}$ when the filter works in training mode and the value of the estimated received symbol $\tilde{b}_{k,l}$ if the receiver operates in decision directed mode (DDM) [4]. By minimizing $\xi_{k,l}$ the MAI component due to multipath is also minimised.

4. MODIFIED MMSE

As was shown in the previous section, the MMSE receiver as shown in Figure 2 can only be used with short spreading sequences, e.g. sequences which span exactly over the duration of one symbol. Moreover the MMSE receiver of [7] only decodes signals which have been spread with a single spreading sequence.

UTRA TDD makes use of two spreading sequences which might span over more than one symbol depending on the value of Q as shown in Figure 1. Figure 3 shows the modified MMSE receiver structure for the case of $Q = 8$. This receiver spans over two symbols and as is shown below, it decodes signals which have been spread using two sequences.

For the case $Q = 8$, $\boldsymbol{v}_l$ of length 16 spans over two symbols, while $\boldsymbol{c}_l$ spans only over one symbol. Therefore two consecutive symbols $b_{k,l}$ and $b_{k+1,l}$ are spread as

$$b_{k,l}\boldsymbol{s}_l^{(1)} = b_{k,l}\begin{bmatrix} c_{0,l}v_{0,l} \; c_{1,l}v_{1,l} \; \dots \; c_{7,l}v_{7,l} \end{bmatrix}^T \tag{7}$$

$$b_{k+1,l}\boldsymbol{s}_l^{(2)} = b_{k+1,l}\begin{bmatrix} c_{0,l}v_{8,l} \; c_{1,l}v_{9,l} \; \dots \; c_{7,l}v_{15,l} \end{bmatrix}^T \tag{8}$$

where the spreading sequence $\boldsymbol{s}_l$ has been divided on two parts $\boldsymbol{s}_l^{(1)}$ and $\boldsymbol{s}_l^{(2)}$. The received signals corresponding to the two transmitted symbols $b_{k,l}$ and $b_{k+1,l}$ are

$$\boldsymbol{r}_k = \sum_{l=0}^{L-1} \sqrt{E_{k,l}}\, b_{k,l}\boldsymbol{s}_l^{(1)} + \boldsymbol{n}_k \tag{9}$$

$$\boldsymbol{r}_{k+1} = \sum_{l=0}^{L-1} \sqrt{E_{k+1,l}}\, b_{k+1,l}\boldsymbol{s}_l^{(2)} + \boldsymbol{n}_{k+1} \tag{10}$$

The structure of Figure 3 can decode $\boldsymbol{r}_k$ or $\boldsymbol{r}_{k+1}$ by choosing the position of the switch. Assuming the filter adapted and having the switch in position 2, $b_{k,l}$ is decoded

$$y = \boldsymbol{w}_2^T\boldsymbol{r}_k \tag{11}$$

where

$$\boldsymbol{w}_2 = \begin{bmatrix} w_8 \; w_9 \; \dots \; w_{15} \end{bmatrix}^T \tag{12}$$

Having the switch in position 1, $b_{k+1,l}$ is decoded

$$y = \boldsymbol{w}_1^T\boldsymbol{r}_{k+1} \tag{13}$$

where

$$\boldsymbol{w}_1 = \begin{bmatrix} w_0 \; w_1 \; \dots \; w_7 \end{bmatrix}^T \tag{14}$$

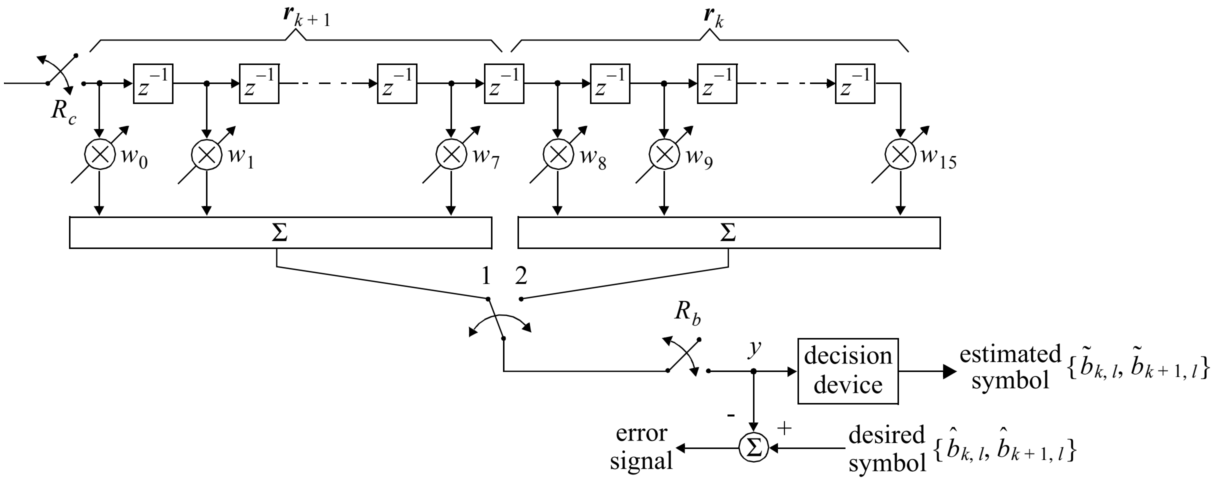

Figure 3: Modified MMSE receiver for $Q = 8$

In this case two values of MSE have to be minimised

$$\xi_{k,l} = \{(\mathbf{w}_2^T \mathbf{r}_k - \hat{b}_{k,l})^2\} \quad (15)$$

$$\xi_{k+1,l} = \{(\mathbf{w}_1^T \mathbf{r}_{k+1} - \hat{b}_{k+1,l})^2\} \quad (16)$$

5. SIMULATIONS

A complex implementation of the structure of Figure 3 was tested in a UTRA TDD environment. A downlink situation was assumed and simulations were carried out for a system with 3 and 5 users with a spreading factor $Q = 8$. The spreading and scrambling codes $\mathbf{c}_l$ and $\mathbf{v}_l$ were taken from [3] for the case of $Q = 8$, with a chip and bit rates of $R_c = 3.84\times10^6$ chips per second and $R_b = 480\times10^3$ bits per second respectively.

The adaptive filter had 16 complex coefficients which were updated using the NLMS adaptive algorithm [8]. This filter decoded data arriving in bursts of type 1 [2]. The filter coefficients where trained during the data burst midamble [2] and fixed to decode the data fields (DDM mode was not used since it does not provide good BER values [9] due to error propagation). The channel used was a multipath fading channel, and simulations were carried out for three different channels, whose propagation conditions were taken from [10] and shown in Table 1.

TABLE 1- Multipath propagation conditions

Case 1, speed 3km/h		Case 2, speed 3km/h		Case 3, speed 120km/h	
Relative delay (nsec)	Average power (dB)	Relative delay (nsec)	Average power (dB)	Relative delay (nsec)	Average power (dB)
0	0	0	0	0	0
976	-10	976	0	260	-3
		20000	0	521	-6
				781	-9

The proposed structure is tested and BER results are obtained as a function of E_c/N_0, where E_c is the chip energy and N_0 is the noise spectral density. Other receiver structures are also tested under the same conditions:

- Traditional receiver of [1] which estimates the phase rotation introduced in the channel during the midamble [2] of the data burst prior to despreading.
- Linear equaliser [4] followed by a traditional receiver.
- RAKE receiver [4] with as many fingers as multipath components. Each of the fingers is supposed to be synchronized to the desired multipath component.

The BER results are shown in Figures 4 - 8. Note that the MMSE receiver outperforms the traditional receiver and the equaliser in most situations. The RAKE receiver provides better results than any other receiver structure in Case 2 as it is the only implementation that can deal with the large excess delay spread of this channel. However, the MMSE receiver can show similar performance or even outperform the RAKE receiver in low noise situations with a high degree of MAI (5 users simulations) for Cases 1 and 3. This is due to the fact that the RAKE receiver does not provide MAI suppression.

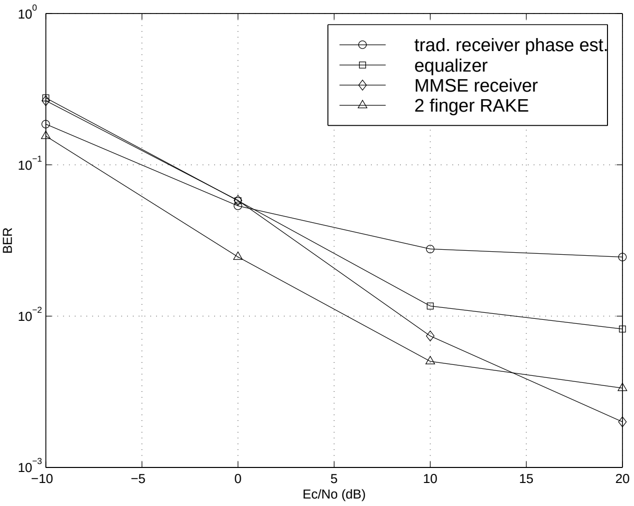

Figure 4: BER vs. E_c/N_0; 5 users; Case 1; $Q = 8$.

6. CONCLUSIONS

A modified implementation of the MMSE receiver to be used in a UTRA TDD environment has been presented, tested and its performance compared with that of a traditional receiver, a linear equaliser and a RAKE receiver. It has been shown that the proposed structure outperforms the traditional receiver and the equaliser for most situations. It has also been observed that it presents similar performance to the RAKE receiver for low noise situations, and even outperforms it for the 5 users case when there is a high level of MAI. Finally it can be observed that the proposed MMSE receiver does not

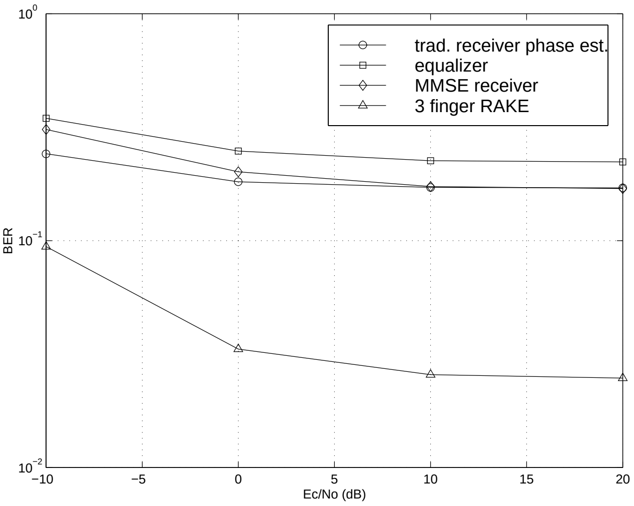

Figure 5: BER vs. E_c/N_0; 5 users; Case 2; $Q = 8$.

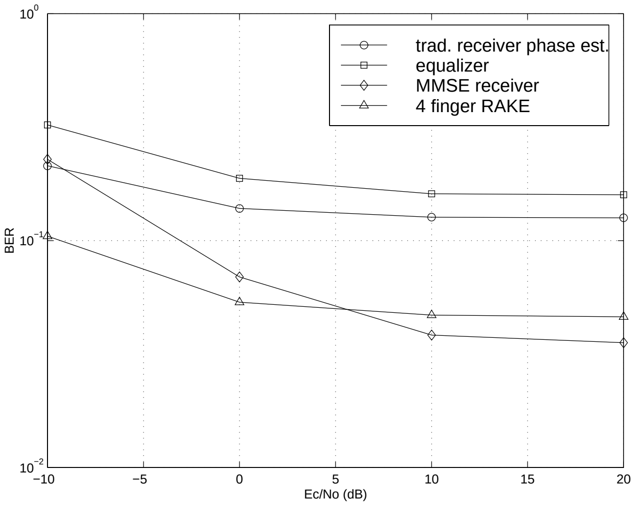

Figure 6: BER vs. E_c/N_0; 5 users; Case 3; $Q = 8$.

work well when the channel shows a large excess delay spread.

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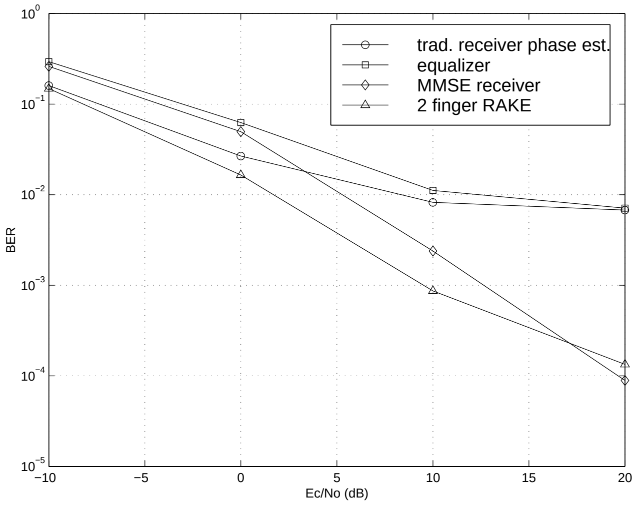

Figure 7: BER vs. E_c/N_0; 3 users; Case 1; $Q = 8$.

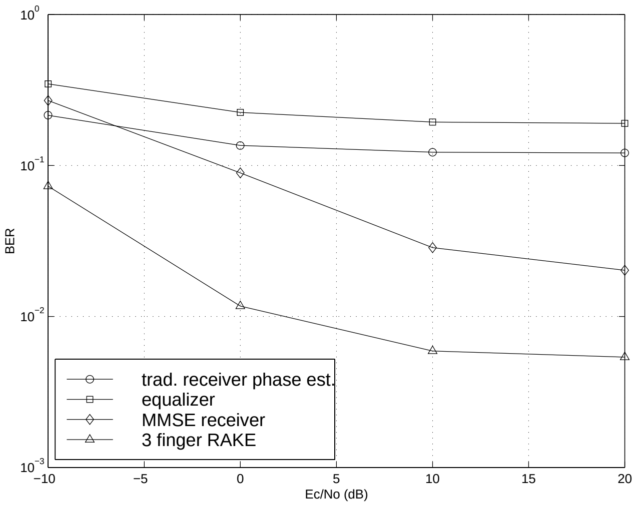

Figure 8: BER vs. E_c/N_0; 3 users; Case 2; $Q = 8$.

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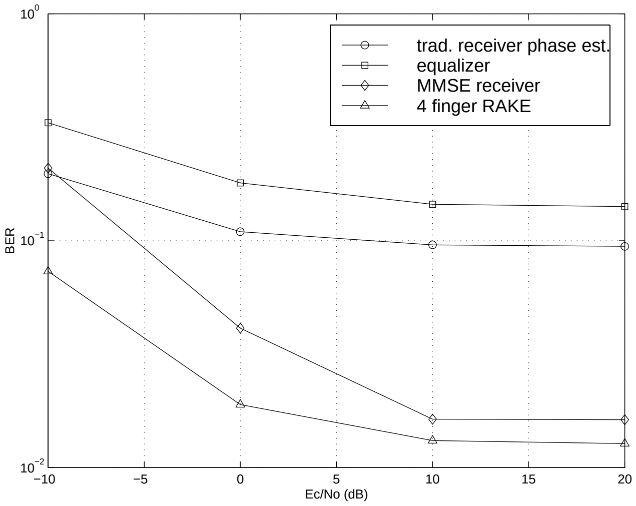

Figure 9: BER vs. E_c/N_0; 3 users; Case 3; $Q = 8$.