A FAST AND ROBUST BLIND DETECTION SCHEME FOR DOWNLINK UMTS TDD COMPONENT

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robust blind multiuser equalisation scheme for the time-division duplex (TDD) component of the universal mobile telecommunication system (UMTS). In addition to the training-based equalisation performed using the midamble, blind detection is introduced over data fields to ensure continuous adaptation and better tracking performance. The latter strategy is mainly based on the affine projection scheme and the concurrent adaptation of both the constant modulus and decision directed modes. In computer simulations the performance of the proposed adaptation strategy is assessed for various UMTS TDD time bursts.

Keywords: concurrent adaptation, affine projection scheme, constant modulus, decision directed, downlink UMTS TDD, spectrum efficiency.

1. INTRODUCTION

The time division duplex (TDD) component of the universal mobile telecommunications system (UMTS) provides a high transmission rate, an efficient use of the spectrum and a flexible capacity allocation. It has previously become the basis for the third generation (3G) standard, and is highly likely to be selected as the main duplex mode operation for fourth generation (4G) systems [1].

The UMTS TDD mode provides uplink and downlink services within the same frequency bandwidth which are separated in time through the use of different time slots as given in Fig. 1(a). In each time slot the contribution of each user, a so-called burst, is a combination of two data fields ,a midamble and a guard period as shown in Fig. 1(b). The midamble is a training sequence used particularly for channel equalisation. In terms of spectrum efficiency, this training sequence is considered as a wasted data, which could represent up to 20% of the whole UMTS TDD physical channel described in [2]. Furthermore, hostile and fast fading channels might significantly degrade the system's performance, whereby a continuous adaptation over the whole time slot would be necessary to ensure acceptable performance.

Blind approaches, which could ensure adaptation over data fields, have been performed using a CM criterion [3, 4].

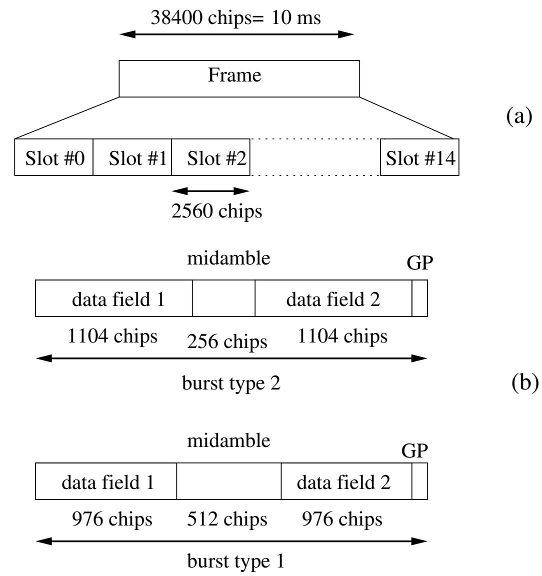

Fig. 1. Time structure in UMTS TDD: (a) basic frame structure, and (b) burst structure.

However, the typical slow convergence of such approaches limits the tracking performance of the receiver. Alternatively, better convergence behaviour can be obtained by using a pilot-assisted scheme such as the strategy proposed in [5]. Nevertheless, the latter scheme is only suitable for partially loaded system where various inactive users can be exploited for pilot loading. Hence, in fully loaded mode fast and robust blind schemes are still required to provide an adequate tracking performance.

In this paper, we aim first to lower the mean square error (MSE) of the algorithm proposed in [4] by operating tow equalisers concurrently similar to [6]. Our second aim is to speed up the convergence of [4] by employing the affine projection algorithm (APA), which is known by its increased convergence speed and to escape from its cost function's local minima [7].

2. UMTS TDD PHYSICAL CHANNEL

In UMTS TDD physical channel time slots are gathered in groups of 15 slots, called frames. Whereby, each frame has a duration of 10 ms [2], as it is shown in Fig. 1(a). Within every time slot a maximum of $N = 16$ users can transmit their signals simultaneously by means of different spreading codes. The contribution of each user is called burst. Burst is a combination of two data fields , a midamble and guard period. Mainly there are two burst types proposed in [2], namely burst type 1 and burst type 2. As illustrated in Fig 1(b), both types have the same length of 2560 chips and ended by guard period of 96 chips, in order to avoid overlapping of consecutive time slots. Burst type 1 has a longer midamble (512 chips) suitable for cases where long training period is required for adaptation and tracking.

3. SIGNAL MODEL

We consider the DS-CDMA downlink system in Fig. 2 with multiple symbol-synchronous users, which for simplicity are assumed to have the same rate. The system is fully loaded with N user signals $u_l[n]$, $l = 0(1)N-1$, which are code multiplexed using Walsh sequences of length N extracted from a Hadamard matrix $\mathbf{H}$. The resulting chip rate signal, running at N times the symbol rate, is further scrambled by $c[m]$ prior to transmission over a channel with dispersive impulse response $g[m]$ and corrupted by additive white Gaussian noise $v[m]$, which is assumed to be independent of the transmitted signal.

The dispersive channel $g[m]$ destroys the orthogonality of the Walsh codes, such that direct decoding of the received signal $r[m]$ with descrambling by $c^*[m]$ and code-matched filtering by $\mathbf{H}^{\mathrm{T}}$ will lead to MAI and ISI corruption of the decoded user signals $\hat{u}_l[n]$, $l = 0(1)N-1$. In order to re-establish orthogonality of the codes, a chip rate equaliser $\mathbf{w}$ can be utilised, whereby the adaptation is performed in both data fields and training period. The equaliser $\mathbf{w}$ consists of a CMA filter $\mathbf{w_c}$ and DD equaliser $\mathbf{w_d}$ operated in parallel, such that $\mathbf{w} = \mathbf{w_c} + \mathbf{w_d}$. In the following, we are concerned to concurrently update $\mathbf{w}$ by implementing the affine projection scheme.

4. MULTIUSER EQUALISATION CRITERION

We first derive the detected users' signals $\hat{u}_l[n]$ as a function of the chip-rate equaliser $\mathbf{w}$. Based on this, we state a suitable cost function on which the equaliser adaptation relies.

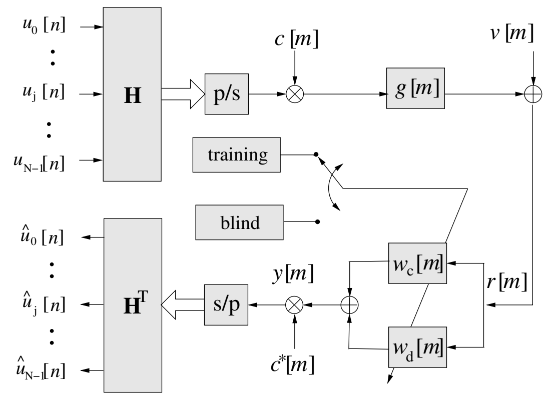

Fig. 2. Signal model.

4.1. Demultiplexed User Signals

For the decoding, Walsh sequences are used as matched filters. The sequence for decoding the lth user, contained in a vector $\mathbf{h}_l$, can be taken from an $N \times N$ Hadamard matrix,

$$\mathbf{H}^{\mathrm{T}} = [\mathbf{h}_0 \;\; \mathbf{h}_1 \;\; \cdots \;\; \mathbf{h}_{N-1}]^{\mathrm{T}}. \tag{1}$$

The lth user is thus decoded as

$$\begin{aligned}
\hat{u}_l[n] &= \mathbf{h}_l^{\mathrm{T}} \cdot \begin{bmatrix} c^*[nN] & & \mathbf{0} \\ & c^*[nN-1] & \\ & & \ddots \\ \mathbf{0} & & c^*[nN-N+1] \end{bmatrix} \cdot \begin{bmatrix} y[nN] \\ y[nN-1] \\ \vdots \\ y[nN-N+1] \end{bmatrix} \\
&= \tilde{\mathbf{h}}_l^{\mathrm{T}}[nN] \cdot \begin{bmatrix} \mathbf{w}^{\mathrm{H}} & & \mathbf{0} \\ & \mathbf{w}^{\mathrm{H}} & \\ & & \ddots \\ \mathbf{0} & & \mathbf{w}^{\mathrm{H}} \end{bmatrix} \cdot \begin{bmatrix} r[nN] \\ r[nN-1] \\ \vdots \\ r[nN-L-N+2] \end{bmatrix}
\end{aligned}$$

whereby the descrambling code $c^*[m]$ has been absorbed into a modified and now time-varying code vector $\tilde{\mathbf{h}}_l[nN]$, and $\mathbf{w} \in \mathbb{C}^L$ contains the equaliser's L chip-spaced complex conjugate weights. Rearranging $\mathbf{w}$ and $\tilde{\mathbf{h}}_l[nN]$ yields

$$\begin{aligned}
\hat{u}_l[n] &= \mathbf{w}^{\mathrm{H}} \cdot \begin{bmatrix} \tilde{\mathbf{h}}_l^{\mathrm{T}}[nN] & & \mathbf{0} \\ & \tilde{\mathbf{h}}_l^{\mathrm{T}}[nN] & \\ & & \ddots \\ \mathbf{0} & & \tilde{\mathbf{h}}_l^{\mathrm{T}}[nN] \end{bmatrix} \cdot \begin{bmatrix} r[nN] \\ r[nN-1] \\ \vdots \\ r[nN-L-N+2] \end{bmatrix} \\
&= \mathbf{w}^{\mathrm{H}} \, \mathbf{H}_l[nN] \, \mathbf{r}_{nN},
\end{aligned} \tag{2}$$

with $\mathbf{H}_l[nN] \in \mathbb{Z}^{L \times (N+L-1)}$ being a convolutional matrix comprising the lth user's modified code vector $\tilde{\mathbf{h}}^{\mathrm{T}}[n]$ and $\mathbf{r}_{nN} \in \mathbb{C}^{N+L-1}$.

4.2. Cost Functions

We assume that the user signals $u_l[n]$, $l = 0(1)N-1$, consist of symbols with a constant modulus γ, such as BPSK,

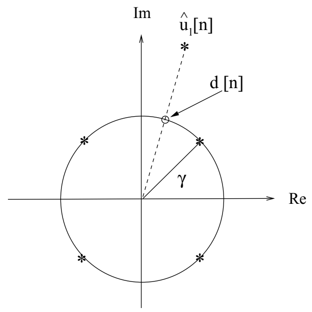

Fig. 3. Configuration of the desired response for the CM criterion, assuming a QPSK constellation

QPSK, or PAM. Therefore, by forcing all decoded users $\hat{u}_l[n]$ onto a constant modulus γ the cost function ξ could be written as [4]

$$\xi = \mathcal{E}\left\{\sum_{l=0}^{N-1}(\gamma^2 - |\hat{u}_l[n]|^2)^2\right\}, \tag{3}$$

where $\mathcal{E}\{\cdot\}$ denotes the expectation operator. In fact, the above CM cost function can be formulated as [7]

$$\xi \;=\; \mathcal{E}\left\{\sum_{l=0}^{N-1}|d_l[n] - \hat{u}_l[n]|^2\right\} \tag{4}$$

$$with \qquad d_l[n] = \gamma\frac{\hat{u}_l[n]}{|\hat{u}_l[n]|}, \tag{5}$$

Hence, the alternative CM philosophy suggests to enforce the detected symbol $\hat{u}_l[n]$ to its nearest symbol $d_l[n]$ from the circle which has the radius γ and the center its origin, as illustrated in Fig. 3. The new form has a structure similar to LMS and generally DD algorithms, whereby the only difference between them is the value of the desired symbol $d[n]$. Tab. 1 shows the various appropriate values of each of the above mentioned algorithms ($q(\cdot)$ maps its input onto the closest constellation alphabet). Here, we are concerned to minimise both ξ_{CM} and ξ_{DD} concurrently. The optimum equalisers coefficient vectors w_c and w_d can be given by

$$\mathbf{w}_{c,\mathrm{opt}} = \arg\min_{\mathbf{w_c}}\xi_{\mathrm{CM}} \text{ and } \mathbf{w}_{d,\mathrm{opt}} = \arg\min_{\mathbf{w_d}}\xi_{\mathrm{DD}}. \tag{6}$$

criterion	MSE	DD	CM
$d[n]$	$u[n]$	q($\hat{u}[n]$)	$\gamma\frac{\hat{u}[n]}{\lvert\hat{u}[n]\rvert}$

Table 1. $d[n]$ for different optimisation criteria.

There are no unique solutions to (6), since minimising ξ_{CM} or ξ_{DD} is ambiguous due to an indeterminism in phase rotation and possible erroneous decisions. However, any member of this manifold is a suitable solution for the equaliser $\mathbf{w}$, and can be used in combination with differential modulation schemes to recover $u_l[n]$.

Example. In this example the two cost functions ξ_{CM} and ξ_{DD} are plotted in Fig. 4 in dependency of an equaliser with a single complex coefficient w_0. The system adopted here is a fully loaded system with $N = 16$ users transmitting their signals over distortionless and delayless channel. The modulation scheme employed here is QPSK with $\gamma = 1$. As shown from Fig. 4, ξ_{CM} exhibits a manifold of optimum solutions satisfying $|w_0| = \gamma$. Yet, only four solutions can be seen in ξ_{DD} due to the four possible QPSK decisions.

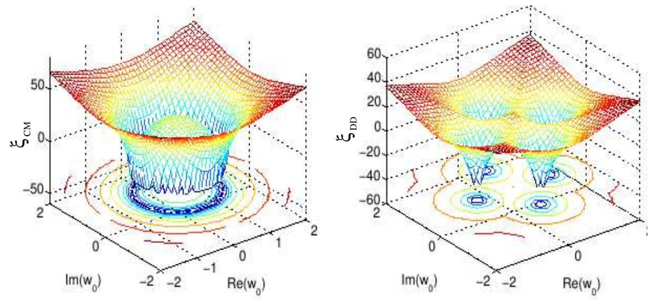

Fig. 4. Cost functions ξ_{CM} and ξ_{DD} in dependency of a single complex valued coefficient w_0.

5. CONCURRENT AFFINE PROJECTION ADAPTATION

In this section we derive the concurrent affine projection algorithm which updates the equaliser taps $\mathbf{w}$. In the pth order APA algorithm, the data at the p latest time instants are explicitly taken into account. Therefore, it is convenient to define $\mathbf{x}_l[n] = \mathbf{H}_l[nN]\mathbf{r}_{nN}$ and $\mathbf{X}_l[n], \mathbf{d}_l[n]$ as

$$\mathbf{X}_l[n] \;=\; [\mathbf{x}_l[n]\;\mathbf{x}_l[n-1]\;\cdots\;\mathbf{x}_l[n-p+1]], \tag{7}$$

$$\mathbf{d}_l[n] \;=\; [d_l[n]\;d_l[n-1]\;\cdots\;d_l[n-p+1]]^{\mathrm{T}} \tag{8}$$

with $\mathbf{d}_l \in \{\mathbf{d}_{l,c}, \mathbf{d}_{l,d}\}$. Hence, the implementation of the pth order algorithm could be summarised as shown in Tab. 2.

where μ_c and μ_d are the relaxation factors and α is a small number used for weighting the identity matrix $\mathbf{I}$. The indicator $\delta(\mathbf{a}) = \mathbf{b}$ is a decision vectorial function. Therefore, $\mathbf{\Lambda}_l[n]$ disables the DD adaptation step for a specific user if the CMA adaptation step leads was to alter the decision.

The convergence of this concurrent scheme is governed by the step sizes in the algorithm. In practice, the DD step size μ_d can be often be chosen much larger than the CMA step size μ_c. However, choosing too large values can cause serious error propagation due to incorrect decisions[6].

pth order concurrent affine projection algorithm
update $,\mathbf{X}_l[n],\ \mathbf{d}_{l,c}[n]$ and $\mathbf{d}_{l,d}[n]$ for $l = 0(1)N-1$
$\mathbf{R}_l^{-1}[n] = (\mathbf{X}_l[n]^{\mathrm{H}}\mathbf{X}_l[n] + \alpha\mathbf{I})^{-1}$
$\mathbf{e}_{l,c}[n] = \mathbf{d}_{l,c}[n] - \mathbf{X}_l^{\mathrm{T}}[n]\mathbf{w}^*[n]$
$\mathbf{w}_c[n+1] = \mathbf{w}_c[n] + \mu_c \sum_{l=0}^{N-1}\mathbf{X}_l[n]\mathbf{R}_l^{-1}[n]\mathbf{e}_{l,c}^*[n]$
$\tilde{\mathbf{u}}_l[n] = \mathbf{X}_l^{\mathrm{T}}[n]\mathbf{w}_c^*[n+1] + \mathbf{X}_l^{\mathrm{T}}[n]\mathbf{w}_d^*[n]$
$\mathbf{\Lambda}_l[n] = \mathrm{diag}(\delta\{\mathbf{q}(\tilde{\mathbf{u}}_l[n]) - \mathbf{d}_{l,d}[n]\})$
$\mathbf{e}_{l,d}[n] = \mathbf{d}_{l,d}[n] - \mathbf{X}_l^{\mathrm{T}}[n]\mathbf{w}^*[n]$
$\mathbf{w}_d[n+1] = \mathbf{w}_d[n] + \mu_d \sum_{l=0}^{N-1}\mathbf{X}_l[n]\mathbf{R}_l^{-1}[n]\mathbf{\Lambda}_l[n]\mathbf{e}_{l,d}^*[n]$
$\mathbf{w}[n+1] = \mathbf{w}_c[n+1] + \mathbf{w}_d[n+1]$

Table 2. Concurrent affine projection algorithm for blind multiuser equalisation.

The potential drawback of DD adaptation is that if the hard decision is incorrect, error propagation occurs which subsequently degrades the equaliser performance. It was shown that if the equaliser hard decision before and after the CMA adaptation are the same then the decision is likely to be correct [6].

6. SIMULATION RESULTS

In order to demonstrate the convergence behaviour of the proposed algorithm, we transmit $N = 16$ QPSK user signals over a noise-free and a dispersive channel $g[m]$, represented by its transfer function $G(z) = 0.93 + (0.28j + 0.19)z^{-1} + 0.1z^{-2}$. The length of the equaliser is $L = 10$, and the relaxation factor $\mu_c = 0.005$. The adaptation is initialised with the first coefficients in both weight vectors w_c and w_d are set to half. The MSE curves of the proposed algorithm on different scenarios over three UMTS TDD bursts are shown in Fig. 5.

As evident from Fig. 5, by operating the proposed algorithm with $\mu_d = 0$ (only CM branch is active) over bursts of type 2 (short training period), a closer MSE performance is reached as compared to case where only training is performed in type 1 (larger midamble). The shortening of the midamble at no performance gain is equivalent to an increase in data throughput of 13%. Furthermore, faster convergence is obtained by either activating the DD equaliser ($\mu_d = 0.01$) or increasing the algorithm's order $p = 3$.

7. CONCLUSIONS

A concurrent affine projection algorithm for blind multiuser equalisation, suitable for UMTS TDD downlink scenario, has been derived. The algorithm provides a continues channel tracking and presents better convergence behaviour over the basic training equalisation even with longer midambles, whereby advantages in terms of data rate and spectrum efficiency can be achieved. The convergence can be accelerated by either activating the DD equaliser or increasing the affine projections algorithm's order.

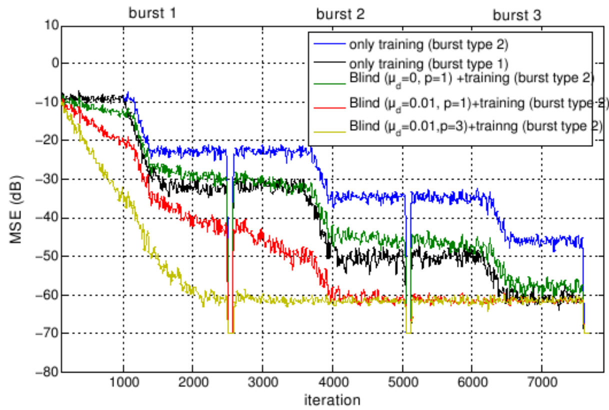

Fig. 5. MSE curves.

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