A NEW UMTS TDD BURST STRUCTURE FOR DOWNLINK PILOT-ASSISTED DETECTION

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Abstract. In this paper, we propose a new homogeneous burst structure for the time-division duplex (TDD) component of the universal mobile telecommunication system (UMTS). The midamble period is removed and replaced by a data field to enhance the system's spectrum efficiency. Alternatively, a pilot signal is loaded into one of these bursts over each time slot, in order to ensure a continuous channel tracking by means of a pilot-assisted adaptation. Computer simulations are used to assess the performance of the adaptation strategy over the proposed time burst.

Keywords: homogeneous burst, pilot-assisted, UMTS TDD, hybrid CM/MSE, 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 high likely will be selected as the main duplex mode operation for the fourth generation (4G)[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. In each time slot the contribution of each user, 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, 5]. 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 strategies proposed in [6, 7]. In the latter [7], various inactive users are exploited for pilot loading to perform a semi-blind adaptation.

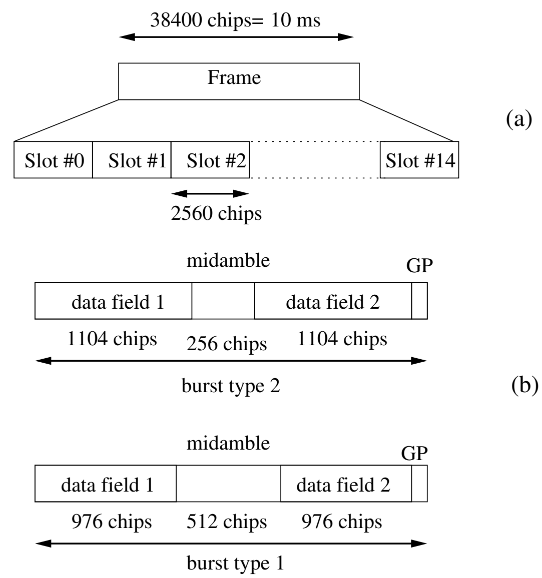

Fig. 1. Time structure in UMTS TDD: (a) basic frame structure, and (b) burst structure.

In this paper, we propose a new time burst structure for the UMTS TDD component, which ensures higher spectrum efficiency than the standard UMTS TDD burst types, and consistent semi-blind adaptation. The adaptation algorithm adopted is a pilot-assisted strategy similar in structure to [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 spread-

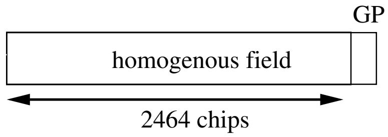

Fig. 2. New burst structure.

ing 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. NEW BURST STRUCTURE

The new burst have a length of 2560 chips with a guard period of 96 chips similar to both burst type 1 and type 2. However, it doesn't consist of any training period and comprises of only one long homogeneous field of 2464 chips, as shown in Fig. 2. Alternatively, in each time slot, one of these new bursts is dedicated to load a signal pilot. The main reason from pilot loading is to ensure a continuous channel tracking rather than a local one such as provided by a training sequence. In fact, in partially loaded scenario, various inactive users could be exploited to load more pilots to enhance system's performance [7]. In terms of spectrum efficiency, a considerable gain in data rate can be achieved by using the homogeneous burst. For example, if we consider a partially loaded system with K active users, where $16 - K$ spreading codes of maximum length are unused, a pilot signal can be loaded by using one of these unused codes. Therefore, using the homogeneous burst instead of burst type 1, a gain of around 26 % in data rate by user basis can be obtained. Furthermore, the maximum number of symbols which can be loaded into one time slot, using the above proposed strategy, is 15×2464 symbols, rather than 16×1952 symbols when burst type 1 is adopted. In another term, the time slot's capacity is increased by approximately 18 %. Another advantage of the new burst is that, unlike the standard bursts no switching required during data transmission. However, the proposed structure may not be efficient in cases of fully loaded systems, where no burst is available for pilot loading and when the number of active users is a small.

4. SIGNAL MODEL

We consider the UMTS-TDD downlink model in Fig. 3 with a maximum of N symbol-synchronous signals, which for simplicity are supposed to have the same rate. We assume

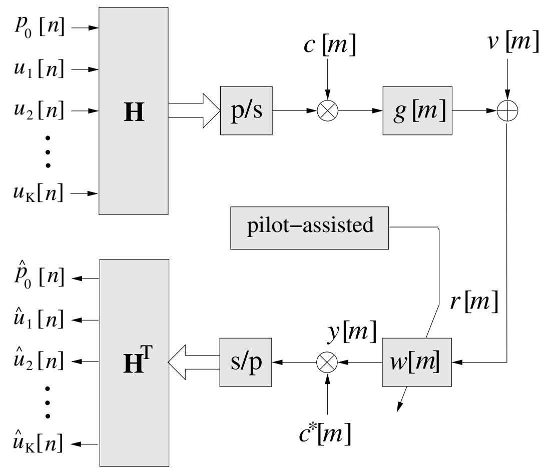

Fig. 3. Signal model.

the first signal $p_0[n]$ to be pilot, and the next $K \leq N-1$ user signals $u_l[n]$, $l = 1(1)K$, to be active, while for the remaining $N-K-1$ inactive signals are assumed to be zeros. The signals $u_l[n]$ 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 corruption by additive white Gaussian noise $v[m]$, which is assumed to be independent of the transmitted signal $s[m]$.

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 multiple access interfernec (MAI) and inter-symbol interference (ISI) corruption of the decoded user signals $\hat{u}_l[n]$, $l = 1(1)K$. In order to re-establish orthogonality of the codes, a chip level equaliser $w[m]$ can be utilised. The equalisation is performed in homogeneous field by using a pilot-assisted strategy. In the following, we are concerned with the pilot-assisted updating of the equaliser coefficients $w[m]$.

5. SEMI-BLIND EQUALISATION CRITERIA

e first derive the detected user signals $\hat{u}_l[n]$ and the pilot signals $\hat{p}_l[n]$ as a function of the equaliser $w[m]$. Based on this, we state suitable cost function based on which the equaliser can be adapted.

5.1. Demultiplexed User and pilot 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,

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

The lth user is thus decoded as

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

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

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

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

and with similar analysis, the lth pilot's demultiplexed signal can be given as

$$\hat{p}_l[n] = \mathbf{w}^{\mathrm{H}}\, \mathbf{H}_l[nN]\, \mathbf{r}_{nN} \tag{3}$$

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

5.2. Cost Function

Since the modulation scheme used for UMTS-TDD is mainly the quadrate phase shift keying (QPSK) (with some exceptions the 8PSK) [2], the K active user signals $u_l[n]$ consist of symbols with a constant modulus γ. Therefore, by forcing all received user symbols $\hat{u}_l[n]$ onto the constant modulus γ and the received pilot symbols $\hat{p}_0[n]$ onto the known transmitted sequences $p_0[n]$, the proposed hybrid cost function ξ can be written as

$$\xi = \mathcal{E}\{\, |p_0[n]-\hat{p}_0[n]|^2\} + \mathcal{E}\left\{\sum_{l=1}^{K}(\gamma^2-|\hat{u}_l[n]|^2)^2\right\} + \\ + \mathcal{E}\left\{\sum_{l=K}^{N-1}|\hat{u}_l[n]|^2\right\} \tag{4}$$

$\mathcal{E}\{\cdot\}$ denotes the expectation operator. Note that The remaining $N-K-1$ inactive users are forced to zeros in MSE sense to ensure that the overall system is fully determined.The equaliser coefficients $\mathbf{w}$ can be determined such that the above cost function is minimised. However, in case where no pilot is loaded, a manifold of solutions exist for an optimum,

$$\mathbf{w}_{\mathrm{opt}} = \arg\min_{\mathbf{w}} \xi \tag{5}$$

There is no unique solution to (5), since minimising (4) is ambiguous due to an indeterminism in phase rotation.

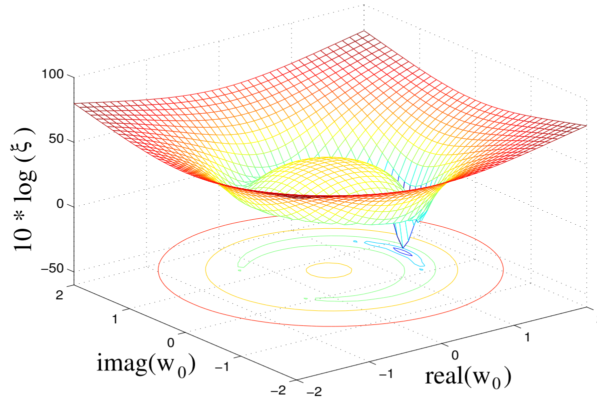

Fig. 4. Cost function ξ in dependency of a single complex valued coefficient w_0, for a fully loaded system with 15 active users and one pilot.

5.3. Phase ambiguity

Since an ambiguity with respect to a complex rotation $e^{j\varphi}$ ($\varphi \in [0; 2\pi]$) cannot be resolved by CM criteria, this rotation invariance could be overcome by loading a pilot signal.

Example. To show how pilots overcome the phase ambiguity the following example is presented. We assume a system with $K = 15$ active users and one pilot, over a distortion-less and delay-less channel $g = 1$. Thus, as shown in Fig. 4, the cost function ξ has one unique optimum solution $w_0 = 1$. Hence the phase ambiguity does not manifest itself any more.

6. SEMI-BLIND ADAPTATION

Simple adaption rules for the equaliser can be obtained by considering stochastic gradient descent techniques, whereby an iterative update rule is utilised for the equaliser coefficient vector $\mathbf{w}_n$ at time n,

$$\mathbf{w}_{n+1} = \mathbf{w}_n - \mu\nabla\hat{\xi} \tag{6}$$

where μ is the algorithm step size, and ∇ the gradient operator applied to instantaneous cost functions $\hat{\xi}$. The instantaneous cost estimates are obtained from (4) by dropping the expectation operation. The gradient term of the instantaneous cost functions can be obtained by using equations (4), (2), and (3) as follows:

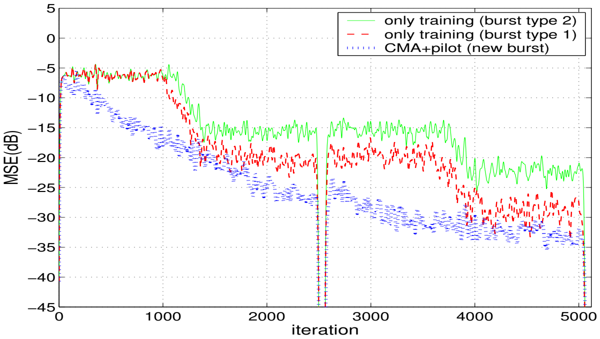

Fig. 5. MSE curves, in 15 active users UMTS-TDD system, of: the proposed algorithm over two homogeneous bursts, equalisation over only midambles of both type 2 (256 chips) and type 1 (512 chips).

$$\frac{\partial \hat{\xi}}{\partial \mathbf{w}^*} = -2\sum_{l=0}^{K-1}(\gamma^2 - |\hat{u}_l[n]|^2)\,\mathbf{H}_l[nN]\,\mathbf{r}_{nN}\,\hat{u}_l^*[n] - \\ -\sum_{l=0}^{N_p-1}\mathbf{H}_l[nN]\,\mathbf{r}_{nN}\,(p_l[n]-\hat{p}_l[n])^* + \\ \sum_{l=K+N_p}^{N-1}\mathbf{H}_l[nN]\,\mathbf{r}_{nN}\,\hat{u}_l^*[n]. \qquad (7)$$

The first term in the algorithm presented by (7), so-called FIRMER CM algorithm[5], differs from the standard CM algorithm [8] or its extension in [3] in the inclusion of a code filtered term $\mathbf{H}_l[nN]\ \mathbf{r}_{nN}$ rather than just the equaliser input $r[n]$. A similar structure has been derived in [9] for purely least mean squares based criterion.

7. SIMULATION RESULTS

Simulations below are performed over downlink UMTS TDD system by using time slots of either burst type 1, type 2 or the the new burst accompanied with the proposed pilot assisted scheme. We first demonstrate the convergence behaviour and later the BER performance

Experiment In order to demonstrate the convergence behaviour of the proposed algorithm over the new homogeneous burst, we transmit $K = 15$ QPSK user signals over the dispersive channel, represented by its symbol rate transfer function $G(z) = 0.93 + (0.28j + 0.19)z^{-1} + 0.1z^{-2}$, in the absence of channel noise. The equaliser length is 10 coefficients, and the adaptation is initialised with the first coefficient in the weight vector set to unity. The step size is experimentally chosen to be about an order of magnitude below the onset of divergence. As it is shown in Fig. 5, the proposed algorithm over the homogeneous bursts outperforms the two other schemes when the equalisation is performed in both burst types but only over the training period. This means that by using the proposed semi-blind equalisation over the new burst structure, at least 26% of the data rate could be gained, hence a much better convergence performance in terms of MSE is achieved.

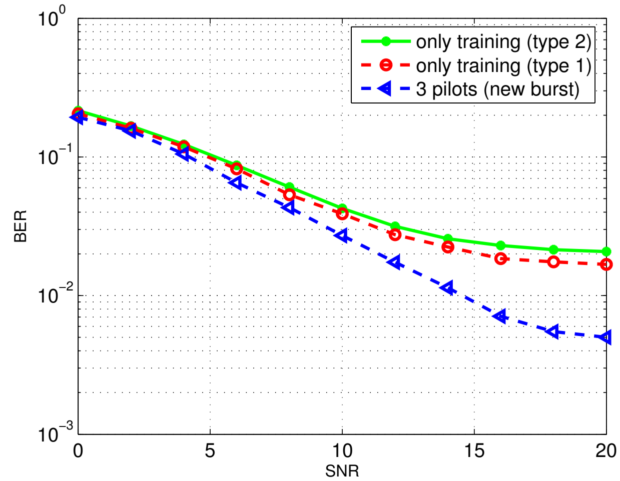

Fig. 6. BER curves, in 13 active users UMTS-TDD system, of: the proposed algorithm over two homogeneous bursts, equalisation over only midambles of both type 2 (256 chips) and type 1 (512 chips).

Experiment 2 To examine the tracking performance of the proposed structure we calculate the average BER of all $K = 13$ active users enhanced by three pilot signals by sending 100 frames over a fast fading Rayleigh channel. The latter channel is a three tap delays 0, 0.26 and 0.52 μs with the corresponding gains 0, -10 and -20 dB respectively. Other parametrs adopted are the carrier frequency $f_c = 2GHz$, the chip duration $T_c = 0.26\mu s$ and a mobile speed of $50km/h$. Note that with the introduction of pilots, no phase correction is needed and the choice of the initial weight vector is not crucial. As shown in Fig.6, by using the proposed pilot-assisted scheme over the new burst outperformes the two other schemes where only training equalisation is applied over either existing bursts type 1 or 2 in terms of BER.

8. CONCLUSIONS AND FULL PAPER

A new homogeneous burst structure with a pilot-assisted equalisation approach for a UMTS-TDD downlink scenario have been presented. The proposed strategy exhibits better convergence behaviour and tracking performance than the basic training equalisation even with longer training period, whereby a gain of data rate and spectrum efficiency have been achieved. It has been shown that the implementation of pilot resolves the typical CM phase ambiguity.

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