Semi-Blind Downlink Inter-Cell Interference Cancellation for FDD DS-CDMA Systems

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Abstract

We adress the problem of downlink interference rejection in a DS-CDMA system. Periodic orthogonal Walsh-Hadamard sequences spread different users' symbols followed by scrambling by a symbol aperiodic base-station specific overlay sequence. The point-to-point propagation channel from the cell-site to a certain mobile station is the same for all downlink signals (desired user as well as the intracell interference). The intercell interference (which can be seen as co-channel interference) degrades significantly the performance of the receiver when the mobile approaches the edge of its cell and the situation becomes more critical at the soft handover. We propose to simultaneously equalize the user of interest while canceling (or reducing) the intercell interferers by the Interference Canceling Matched Filter (ICMF) receiver which we introduced previously. We can get ride of the intracell interference by the maximum SINR receiver following the ICMF. The ICMF depends on the common channel for the cell of interest, to be estimated with a pilot sequence, and contains a blind interference cancellation part. The critical part is the channel estimation. The usual correlation method may lead to poor estimates in high interference environments. Significant improvements result from the exploitation of the sparceness of the propagation channel model.

1. Introduction

Wireless communications are showing an unpredicted growth and the advent of third generation system will open up the range of possible services and will significantly increase the available data rates. In the shift from voice services to data services, not only an increase in data rate is required but also a decrease in bit error rates. To achieve such data rates at such bit error rates, multiple access interference cancellation will be required. Such interference is indeed a major impairment in wireless systems.

In the 3GPP proposal, the synchronous downlink users are scrambled by a random scrambling sequence in order to reduce the interference from the neighboring base stations while keeping the orthogonality of the Walsh-Hadamard codes. However, this interference cancellation scheme is very limited at the soft handover and/or in the presence of untolerable power control errors. In such a situation, the inter-cell interferers (seen also as co-channel interferers in a TDMA system) can not be ignored and the performance of a single-user receiver (example the RAKE receiver) decreases significantly.

When the mobile is equipped with multiple sensors, the spatio-temporal processing becomes possible and significant impovements can be reached as we have showed in [1]. As we discussed in [2], many spatio-temporal receivers suffer from complexity problems and may require a long training sequence to estimate the necessary parameters. This was our motivation to introduce the ICMF [2] and propose several methods for its implementation [3, 4] based on the pulse shaping filter prior knowledge and/or on the characteristics of the system. Further improvements can be obtained by exploiting the sparceness nature of the propagation channel where the channel parameters are divided into slowly and fast varying. The former, required by the ICMF structure, can be estimated independently over a long period of the received signal and the latter are the maximal ratio combining (MRC) coefficients estimated by a short training sequence. Since the (pathwise ICMF) receiver is only optimal for sufficiently separated paths, we propose to equalize the pulse shaping filter prior to the interference canceler.

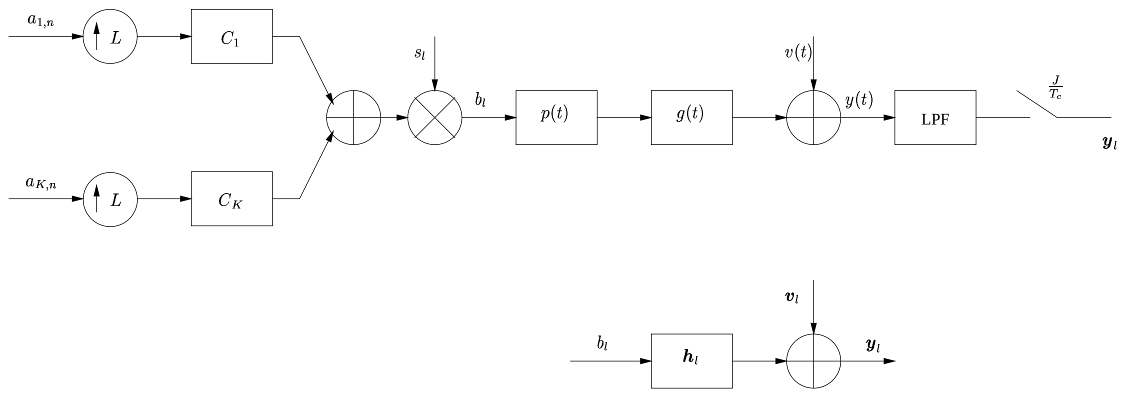

Figure 1. Downling signal model

2. Data Model

The intracell and intercell users are assumed to transmit linearly modulated signals over a linear multipath channel with additive Gaussian Noise. For the clarety of the presentation, we consider first the downlink channel model for a single cell (see Fig. 1).

It is assumed that the signal is received at the mobile station through multiple discrete-time channels obtained from oversampling the received signal with respect to the chip rate or through multiple antennas (or a combination of the two schemes). The symbol and chip periods T and T_c are related through the spreading factor $L = \frac{T}{T_c}$ which is assumed here to be common for all the users. The total chip sequence b_l is the sum of the chip sequences of all the users, each one given by the product of the nth symbol of the kth user and an aperiodic spreading sequence $w_{k,l}$ which is itself the product of a periodic Walsh-Hadamard (with unit energy) spreading sequence $c_k = [c_{k,0}\, c_{k,1}\, \cdots c_{k,L-1}]^T$, and a base-station specific unit magnitude complex scrambling sequence s_l with variance one, $w_{k,l} = c_{k,\lfloor \frac{l}{L} \rfloor} s_l$:

$$b_l = \sum_{k=1}^{K} b_{k,L} = \sum_{k=1}^{K} a_{k,\lfloor \frac{l}{L} \rfloor} w_{k,L}. \qquad (1)$$

The scrambling operation is a multiplication of chip rate sequences. The spreading operation could be represented similarly, or alternatively as a filtering of an upsampled symbol sequence with the spreading sequence as impulse response, as in dicated in Fig. 1. The chip sequence gets transformed into a continuous-time signal by filtering it with the pulse shape $p(t)$ and then passes through the multipath propagation channel $g(t)$ to yield the received signal $y(t)$. We assume that the mobile terminal is equiped with an antenna array with Q elements. Furthermore, we assume a specular model for the spatio-temporal channel. The common channel impulse response for all the users is given by

$$\boldsymbol{g}(t) = \sum_{m=1}^{M} E_m \boldsymbol{a}(\theta_m)\delta(t - \tau_m) \qquad (2)$$

where $\boldsymbol{g}(t)$ and $\boldsymbol{a}_m = \boldsymbol{a}(\theta_m)$ are vectors of dimension Q, the number of sensors employed at the receiver. $\boldsymbol{a}_m$ defines the response of the antenna array and is a function of the Direction of Arrival (DoA), θ_m, of mth path. Furthermore, the specular channel is characterised by E_m and τ_m, the complex amplitude and the path delay respectively. M is the number of specular paths. The channel parameters can be divided into two classes: fast and slowly varying parameters. The slowly varying parameters are the delays τ_m, the DoA θ_m and the short-term path power $\mathrm{E}|E_m|^2$. Hence, the fast parameters are the complex phases and amplitudes E_m. We shall emphasize on the fact that the delays do not correspond necessarily to the physical delays but they can be chosen among a discrete set uniformly spaced by at most $\frac{T_c}{4}$ for a root-raised cosine waveform with a roll-off factor of 0.22.

Sampling the lowpass-filtered continous-time received signal

$$\boldsymbol{y}(t) = \sum_{l=-\infty}^{+\infty} b_l \sum_{m=1}^{M} E_m \boldsymbol{a}_m p(t - \tau_m - lT_c) + \boldsymbol{v}(t) \qquad (3)$$

at instants $t = t_0 + kT_c + n\frac{T_c}{J}$ and stacking the J samples corresponding to the duration of a chip period, we get for the discrete-time signal model

$$\boldsymbol{y}_k = \widetilde{\boldsymbol{A}} \sum_{i=-R}^{R+l} b_{k-i} \boldsymbol{P}_i \boldsymbol{e} + \boldsymbol{v}_k = \mathbf{h}(q) b_k + \boldsymbol{v}_k \qquad (4)$$

where $\boldsymbol{y}_k = [\boldsymbol{y}_{k,0}, \cdots, \boldsymbol{y}_{k,J-1}]^T$, ^{T} indicating the matrix transpose, $\boldsymbol{y}_{k,i} = p(t_0 + kT_c + \frac{i}{J}T_c)$, $\widetilde{\boldsymbol{A}} = \boldsymbol{I}_J \otimes [\boldsymbol{a}_1 \cdots \boldsymbol{a}_M]$, $\boldsymbol{I}_J$ denote identity matrix of dimension $J \times J$,

$\boldsymbol{e} = [E_1 \cdots E_m]^T$, $\boldsymbol{v}_k$ is defined as $\boldsymbol{y}_k$, q is the delay operator (i.e. $q\boldsymbol{y}_k = \boldsymbol{y}_{k-1}$), $\mathbf{h}(z) = \sum_{i=-R}^{R+l} \boldsymbol{h}_i z^{-i}$ is the common channel for all the intracell users, $\boldsymbol{h}_i = \widetilde{\boldsymbol{A}}\boldsymbol{P}_i\boldsymbol{e}$ and

$$\boldsymbol{P}_i = \begin{bmatrix} \boldsymbol{P}_{i,0} \\ \vdots \\ \boldsymbol{P}_{i,J-1} \end{bmatrix} \quad (5)$$

where $\boldsymbol{P}_{i,n} = diag(p_{1,n} \cdots p_{M,n})$ is an $M \times M$ diagonal matrix and $p_{m,n} = p(t_0 + iT_c + n\frac{T_c}{J} - \tau_m)$. We have used in (4) a finite impulse response (FIR) concatenation of the pulse shape $p(t)$ to $\pm RT_c$ hence rendering the overall channel response finite. Due to the delay spread of the multipath channel $\boldsymbol{g}(t)$, the transmitted symbols are spread out in time over the duration of possibly several symbol periods. Assuming that the maximum delay spread τ_{max} experienced in the channel $\boldsymbol{g}(t)$ is known, a processing window of length $2R + l + 1$ (where $l = \left\lceil \frac{\tau_{max}}{T_c} \right\rceil$) chip periods for the receiving filter will guarantee to capture the entire contribution of a certain data chip b_l.

If we model the scrambling sequence and the symbol sequences as independent and identically distributed (i.i.d.) sequences then the chip sequence is a sum of K independent white noise (chip rate i.i.d. sequences, hence stationary). The intracell contribution to $\boldsymbol{y}_k$ then is a stationary (vector) process (the continuous-time counterpart is cyclostationary with chip period). The intercell interference is a sum of contributions that are of the same form as the intracell contribution. The remaining noise is assumed to be white stationary noise. Hence, the sum of intercell interference and noise, $\boldsymbol{v}_k$, is stationary.

Finally, we shall note that the problem traeted in this paper is similar to co-channel interference cancellation for TDMA standards where the chip sequence b_l gets replaced by a symbol sequence for the user of interest and the common downlink intercell channels are the co-channel interferers.

3. Interference Canceling Matched Filter

It is well known that the optimal receiver for the detection of one chip in the presence of Gaussian noise is the (multi-channel) Maximum-Likelihood Sequence Estimation (MLSE) which can be implemented efficiently by the Viterbi Algorithm (VA). When the noise contains multiaccess interference that can be modeled by Gaussian process, the noise correlations induce a certain weighted metric to be used in the VA. In [2], we have shown that, especially when the number of the channels (JQ) exceeds the number of co-channel cells, such MLSE performs not only equalization but also interference cancellation. Using the Interference-Canceling Matched Filter (ICMF) introduced in [2], the interference cancellation operation can be separated in a first receiver stage that concentrates the multichannel information into a single channel, on which equalization can then be performed (Fig. 2). In Fig. 2, the maximum SINR receiver ([5] and references therein) is used to perform chip-rate equalization then symbol detection of the user of interest. As pointed out in [5], the intracell interference is removed at the last (correlation) step due to the orthogonality of the users' codes.

The ICMF is parameterized by the channel impulse response of the cell of interest that can be estimated by the primary common pilot sequence [6] and a Wiener filter that can be estimated blindly over a long stretch of the received data. The channel estimation is the critical part in the ICMF and especially in the second branch (i.e. blocking equalizers branch) where we used a linear parameterization of the noise subspace in terms of the unstructured channel impulse response coefficients [3, 4]. When the quality of the channel estimate is not good enough (in a high interference scenarios such as the soft handover) because only a short training sequence is available at the mobile terminal, the blocking equalizers passes a significant part of the desired signal which degrades significantly the performance of the Wiener filter. However, when the channel estimation is perfect, even a short Wiener filter can reduce the interference.

The filter $\mathbf{f}(z)$ Which is a (MMSE) Linear equalizer of $\mathbf{h}^\dagger(z)\mathbf{h}(z)$ must be estimated at the rate of the variation of the channel. We shall in the following improve the implementation of the ICMF by relaying only on the slow parameters of the channel impulse response which can be estimated by averaging over a long stretch of signal. Then, the remaining (fast) parameters can be estimated by the short training sequence. This observation motivates pathwise interference cancellation which only requires the knowledge of the slowly varying parameters as opposed to to the standard approach which requires complete knowledge of the channel. Hence, in the pathwise scenario, the interference cancellation takes place between individual multipath components, typically, before they are spatio-temporally recombined. The obvious advantage of an interference cancelling filter that relies only on slow parameters, τ_m and $\boldsymbol{a}_m$ as a function of the DoA θ_m is that the adaptation requirements of the filter also will be based on the rate of change of the slow parameters which are easier to estimate as well as to relax the update rate of the adaptive interference canceling filter, hence reducing the complexity of the filter. Furthermore, a pathwise filtering approach allows improved channel parameter estimation since the estimated path components contain the signal of interest with an improved SINR compared to the received signal.