A HIGHER-ORDER-STATISTICS BASED BLIND INTERFERENCE CANCELLATOR FOR ASYNCHRONOUS DS/CDMA SYSTEMS

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ABSTRACT

In this work[1], a novel DS/CDMA receiver using a High Order Statistics (HOS)-based interference cancellator is presented. In particular, the use of the Shen-Nikias algorithm for multilevel signal estimation in interference-dominated communication systems is proposed. The information signal coming out from the matched filter receiver can be regarded as a multilevel signal corrupted by heavy interference due to other system users (multi-user interference) or introduced by external noise sources. In the proposed analysis we considered only the presence of multi-user interference together with AWGN noise. A heuristic, however reasonable, assumption about the autoregressive nature of the multi-user interference is considered in the paper. BER performance analysis evidences a clear improvement with respect to the conventional matched filter case, thus confirming the validity of the basic assumptions made about statistical properties of MUI and proposing HOS-based techniques as valuable alternatives to other state-of-the-art DS/CDMA detection algorithms.

1. INTRODUCTION

During this last decade, the application range of Spread Spectrum and CDMA techniques [1] grew very much, covering various fields like e.g.: wireless LANs, mobile telephony (North-American IS-95 standard [1]), mobile multimedia networks (wideband-CDMA is the core of the transmission level of UMTS [2]), satellite networks, etc.

The great advantage of CDMA is the possibility of providing fully asynchronous transmission, allowing a certain number of users to share the same bandwidth without any time and frequency constraint [1]. Nevertheless such advantages, resulting in terms of improved flexibility and real-time multiple access management are in trade-off with the capacity limitation involved by CDMA self-interference (namely: multi-user interference [13] or MUI), and by external man-made interferences. The ideal target of a DS-CDMA receiver is to completely erase MUI and external interference, in order to reduce the noise to the AWGN one. This result could be ideally reached in case of absolutely synchronous transmission using orthogonal spreading sequences such the ones belonging to the Hadamard-Walsh set [1]. Of course, this is an ideal situation that cannot be reproduced in most of real-world wireless applications. For these reasons, other typologies of DS-CDMA receiver schemes have been proposed in order to mitigate the MUI effects. Multi-user Detection (MUD) is one of most relevant research fields in Spread Spectrum communications. De-correlating receivers, MMSE receivers, serial and parallel interference cancellators, neural network-based receivers are well-known examples of MUD schemes for DS-CDMA applications (see e.g. [3] for an exhaustive panoramic of the most relevant MUD topics). Problems of MUD schemes are mainly related to the huge computational complexity preventing their practical application. Moreover, MUD algorithms are devoted at removing only MUI, but are irrespective to other kind of noises able at severely disturbing CDMA signals and compromising capacity performances. Interesting works related to the cancellation of external interference based on cyclostationarity properties of DS-CDMA signals are shown in [10] and [11]. In this paper, the use of a method is considered that is based on Higher-Order Statistics (HOS) [4] in order to detect the information signal of a DS/CDMA user corrupted by MUI and external interference. The use of HOS and statistical-hypothesis testing methods were introduced in DS-CDMA applications for accurate BER performances estimation in the few-user case [7][8] and for coarse PN acquisition [9]. The starting point of the proposed analysis consists in the *Shen-Nikias algorithm* [5]. Such an algorithm was originally proposed for estimating a weak multilevel signal in non-Gaussian impulsive noisy environment, making the assumption of α-stable distribution for the background noise. Further on, the algorithm was successfully applied under the hypothesis of parametric Generalized Gaussian distribution of the background noise [6], thus extending the application range to all kind of non-Gaussian noises, not only limiting to the heavy-tailed case.

Without loss of generality, we can regard the output of a DS/SS matched filter receiver as multilevel signal corrupted by different interfering signals, i.e. self-generated interference (MUI) and external interference. When the number of users is very high (as often happens in real-world applications) or the external interference is very harsh, the information-bearing signal is surely "weak" with respect to background interference, that is the basic hypothesis of the Shen-Nikias algorithm.

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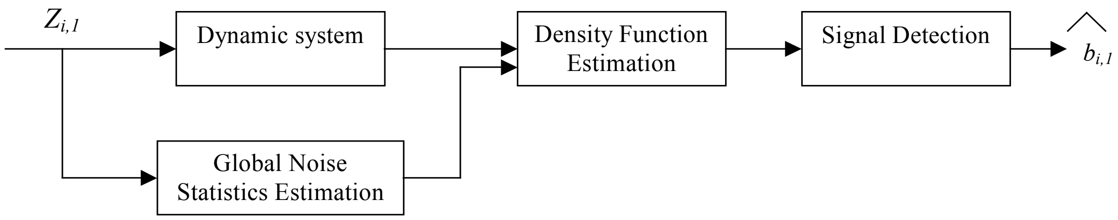

Figure 1. *The proposed DS/CDMA receiver scheme with HOS-based interference cancellator*

Moreover, it was shown in [7] that a symmetric Generalized Gaussian (GG) distribution could model in an effective parametric way the non-Gaussian behaviour of global DS-CDMA noise. A basic assumption about the autoregressive characterisation of MUI has been performed so to validate the use of the recursive Shen-Nikias estimator applied to the DS-CDMA reception. These are some of the key motivations and hypothesis underlying to the experiment shown in the paper, i.e. the exploitation of Shen-Nikias algorithm for cancelling *all* kind of non-Gaussian interference disturbing the wanted signal in an asynchronous DS-CDMA transmission system. Even if we limited the analysis only to the MUI mitigation, the proposed analysis can be straightforwardly extended to the generic case related to the presence of MUI and external interference, provided an accurate estimation of the noise statistics in terms of variance and normalised kurtosis, which are the basic statistical parameters needed for defining the GG distribution model. The paper is organised as follows. In section 2, the system model is presented, in the section 3 the proposed HOS-based detection method will be explained. Section 4 is devoted to the performances analysis, finally concluding remarks are given in section 5.

2. SYSTEM MODEL

Let us consider a generic asynchronous DS-CDMA system employing a two-level BPSK modulation. Let spreading factor be fixed equal to *N*. The receiver is devoted to recovering the information signal transmitted by each user. The de-modulation and despreading blocks implement carrier recovery, PN acquisition and tracking algorithms in order to ensure the correct receiver synchronisation. The following notation will be adopted in the following of the paper:

- K is the number of transmitting users;
- P is the transmitted power. We assume that the channel is additive and does not introduce distortion;
- $b_k(t) \in \{-1,1\}$ is the bit stream transmitted by the k-th user. Each bit has a duration equal to T. The bit-rate is fixed to 64Kb/s;
- $c_k(t) \in \{-1,1\}$ is the spreading code of the k-th user. A binary 63-chip-length Gold code was used for spreading [12];
- $n(t)$ is the Gaussian noise with two-sided power spectral density $N_0/2$ (W/Hz);
- $\xi(t)$ is an external interfering signal added by the channel, regarded here as a generic stochastic process;
- τ_k and ϕ_k are the asynchronous transmission delay and phase delay respectively of the k-th interfering user, usually regarded as random variables uniformly distributed in [0,T) and [0,2π) [13].

After PN synchronisation and de-spreading operation the i-th signal sample received by the reference user (for sake of simplicity, we suppose user #1) has the following expression [1][13]:

$$Z_{1,i} = \sqrt{\frac{P}{2}} T b_{1,i} + I_{K-1,i} + \xi_{1,i} + \eta_{1,i} \quad t \in [iT, (i+1)T) \quad (1)$$

where:

$$I_{K-1,i} = \sqrt{\frac{P}{2}} \sum_{k=2}^{K} \left[\int_{iT}^{(i+1)T} b_k(t-\tau_k) c_k(t-\tau_i) c_1(t) dt \right] \cos\phi_k \quad (2)$$

is the multi-user interference (MUI), and:

$$\xi_{1,i} = \int_{iT}^{(i+1)T} \xi(t) c_1(t) dt \quad (3)$$

$$\eta_{i,1} = \int_{iT}^{(i+1)T} n(t) c_1(t) dt \quad (4)$$

are the filtered components of the external interference and of the AWGN noise It is known from [13] that the Gaussian sequence $\{\eta_{i,1}\}$ is formed by independent and identically distributed samples with zero mean and variance $N_0 T/4$. Starting from this model, we can explain how the proposed HOS based interference cancellator works, by considering, at the present moment, only the presence of Gaussian AWGN noise and MUI, thus neglecting the contribution of the external interference $\xi(t)$.

3. THE HOS-BASED INTERFERENCE CANCELLATOR

The proposed receiver scheme exploiting the Shen-Nikias algorithm for interference cancellation is depicted in Figure 1. We can reduce the detection of the binary signal of the reference user as a problem of multilevel digital signal estimation, that can be mathematically formalized as pointed in [5][6]. The sample sequence $\{Z_i\}$ provided as output by the conventional matched filter stage is regarded here as the observation vector [5][6]. The dynamic system model is regarded as a scalar state-space system with the following equations [4]:

$$X_{i+1} = A_i X_i + W_i \quad (5)$$

$$Z_i = H_i X_i + V_i \quad (6)$$

where $\{W_i\}$ is the independent and identically distributed (i.i.d.) noise sequence assumed with Generalised Gaussian density function, and $\{V_i\}$ is the signal sequence to be estimated, in our case, the binary signal sequence transmitted by the reference user $\{\sqrt{P/2}Tb_{1,i}\}$. The two sequences $\{W_i\}$ and $\{V_i\}$ are assumed to be mutually independent. As previously mentioned, the noise sequence is regarded as the global DS/CDMA noise, i.e.:

$$W_i = I_{K-1,i} + \eta_{1,i} \quad \mathrm{i} = 1,2,... \quad (7)$$

In [5] the interference sequence is regarded as an AR sequence driven by a stochastic process with a particular density function. In our case this process is identified with the channel Gaussian noise, whereas $\{X_i\}$ is the multi-user interference. Our assumption is that the term related to MUI is autoregressive (AR), so to make reasonable the application to the considered case of the Shen-Nikias recursive estimator. This heuristic assumption is made on the basis of the MUI expression provided in [13]:

$$I_{K-1,i} = \sum_{k=2}^{K}\left[b_{k,i-1}R_{k,1}(\tau_k) + b_{k,i}\hat{R}_{k,1}(\tau_k)\right]\cos\phi_k \quad (8)$$

where $R_{k,1}$ and $\hat{R}_{k,1}$ are the partial cross-correlation functions between the PN spreading sequences of the user k and the reference user respectively, defined in [12][13]. This term can be regarded as an auto-regressive, in fact it presents a dynamic evolution depending on the values of the transmitted bit at the time instants *(i-1)T* and *iT*.

Let $\{Z^i\} = \{Z_1, Z_2, ..., Z_i\}$ the set of possible observations up to time i; for any fixed i, the set of past measurement $z^i = \{z_l : Z_l = z_l, l = 1,2,...i\}$ is given [5][6]. The interference sequence $\{X_i\}$ to be estimated is an AR sequence driven by the non-Gaussian process $\{W_i\}$ [5]. The objective of the signal estimation algorithm is finding the optimal estimation $\{\hat{X}_i\}$ of $\{X_i\}$, thus removing the interference from observation and recover the wanted signal [5][6]. Among the different recursive estimators, we selected the method proposed by Shen and Nikias in [5], using a Generalised Gaussian pdf model for the noise sequence as pointed in [6]. This choice was motivated by the considerations made in [7] about the suitability of a GG model for describing the non-Gaussian behaviour of global DS/CDMA noise. In the scheme shown in Figure 1, the received signal after de-spreading is sent to a block of statistical estimation of the global DS/CDMA noise, required for deriving the non-Gaussian GG modelling, i.e. *variance* (2nd order statistic) and *normalized kurtosis* (4th order statistic [4]). The mathematical computation of the GG model parameters as a function of estimated variance and normalized kurtosis is widely dealt in [14]. After this noise-modelling step, the estimated statistical parameters and the received signal are sent together into the block that realises the Shen-Nikias estimation algorithm, which is based on the computation of the a-posteriori pdf, i.e. $p_{X_i/z^i}(x_i/z^i)$. Then, the *Absolute Value Criterion* (AVC) [5][6] is applied in order to derive the optimal estimation of $\{X_i\}$. The AVC procedure execution steps are fully detailed in [5] and [6].

4. NUMERICAL RESULTS

The performances of the proposed interference cancellation algorithm are evaluated here in terms of Bit Error Rate (BER). The proposed receiver scheme has been set up and simulated in MATLAB 6.0 environment. The transmission signal to noise ratio (*SNR*) ranges from 0dB to 15dB. A bit-stream sequence with length N = 10000 bits has been used and results have been obtained for a different number of interfering users K. In particular, simulations have been carried on for K=12, K=16, and K=20 asynchronous users. The dynamic system parameters has been fixed at the values A_i=0.7 and H_i=1.0 for each run and for each discrete time instant i. Using these experimental conditions, results have been obtained which are shown in figures 2, 3, 4. From graphical results shown, it is possible to note a significant improvement in terms of BER obtained by the receiver scheme using in addition the HOS-based interference cancellator (solid line), with respect to the ones provided by the conventional matched filter receiver (dashed line).

Such improvement is particularly relevant when the system is dominated by non-Gaussian MUI, thus confirming the effectiveness of Shen-Nikias algorithm for interference cancellation. In fact, the HOS-based interference cancellator is adapted with respect to the noise distribution after despreading. The improvement is less relevant at low SNR values, when the system is dominated by AWGN noise. However, the performances are always better than ones obtained in the case of using the conventional matched filter receiver. Preliminary results shown seem to be comparable with ones provided by other blind MUD detection algorithms (like e.g. LMMSE [3]), with a reasonable computational weight.

5. CONCLUSIONS AND FUTURE PERSPECTIVES

In this paper, the application of the recursive Shen-Nikias algorithm for multilevel signal estimation to the efficient signal detection in asynchronous DS-CDMA systems has been proposed and discussed. The Shen-Nikias algorithm is able to recursively estimate the interference corrupting the received bitstream; this kind of approach is able to mitigate the multi user interference corrupting the wanted signal after despreading. From the shown results, it is evident that the proposed scheme is more efficient with respect to a conventional matched receiver. The heuristic assumption about the AR characterization of MUI, to be proven in a more formal way, can find a first experimental validation by the achieved simulation results. In the present work, only the MUI cancellation has been considered, but the same scheme can be exploited also for performance enhancement of asynchronous DS-CDMA systems also in presence of external interference sources, with strongly non-Gaussian characterisation. The effectiveness of the proposed approach greatly depends on the accurate modelling of the global DS-

CDMA noise in terms of pdf, and hence by the accurate statistic accumulation. Future problems to be faced in future works might concern with the effective statistic estimation of global DS-CDMA noise when non-stationary disturbances are present in the system.

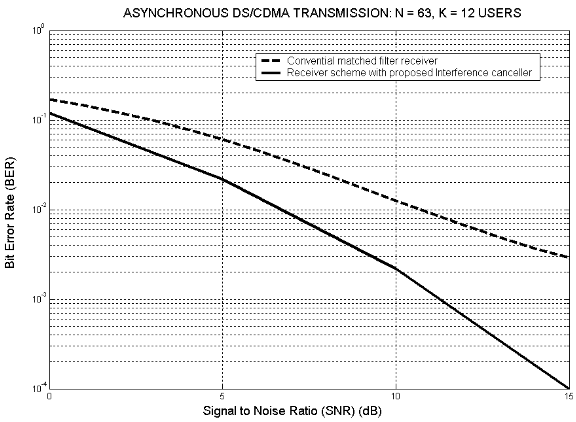

Figure 2. *BER results of the proposed detection scheme compared with the conventional receiver with K=12 users.*

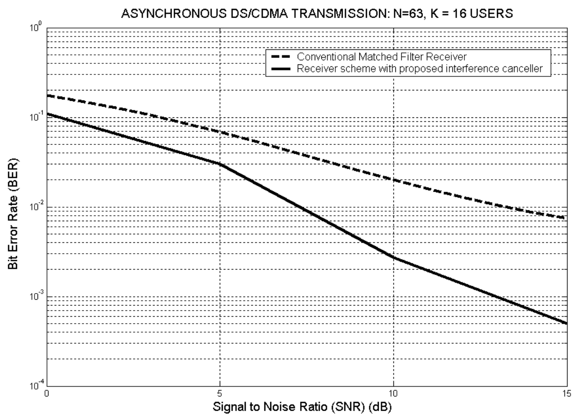

Figure 3. *BER results of the proposed detection scheme compared with the conventional receiver with K=16 users.*

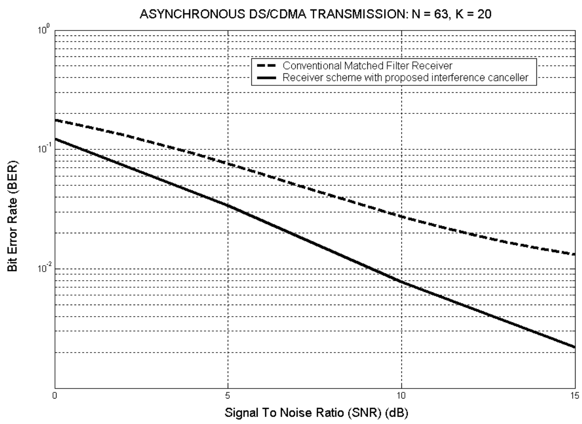

Figure 4. *BER results of the proposed detection scheme compared with the conventional receiver with K=20 users.*

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