Progress In Electromagnetics Research Letters, Vol. 3, 141–150, 2008

NARROW-BAND INTERFERENCE SUPPRESSION IN CDMA SPREAD-SPECTRUM COMMUNICATION SYSTEMS USING PRE-PROCESSING BASED TECHNIQUES IN TRANSFORM-DOMAIN

P. Azmi and N. Tavakkoli

Electrical Engineering Department
Tarbiat Modares University
Iran

Abstract—In this paper, we present two pre-processing based techniques in unitary transform-domain for narrow-band interference rejection in CDMA communication systems. In our techniques, by using Karhaunen-Loeve Transform (KLT) and Discrete Fourier Transform (DFT), at the transmitter, eigenvectors occupied by NBI are determined; then the energy of the transmitted signal is set to zero into the direction of those determined vectors. Hence, any information is not deleted by NBI through channel. As a result after applying these transforms, a major part of the processing would be shifted to the transmitter, and thus complexity of receiver is reduced. Our simulation results show that the proposed methods improve the performance of the CDMA communication systems in the presence of narrow-band interference.

1. INTRODUCTION

Direct-Sequence Code-Division Multiple-Access system (DS-CDMA) is considered as a proper method in cellular communication systems. Furthermore, DS-CDMA for these communication systems is capable to share the bandwidth with Narrow-band communication systems without undue degradation of either system's performance [1].

Receiver of CDMA communication systems faces with many types of interference such as multi-user interference (MUI) caused by the other spread-spectrum users in channel, and narrow-band interference (NBI) caused by coexistence with conventional communications. Noticeable performance degradation is observed in situations where the interfering signal is much stronger than the useful ones [2].

The performance of a DS-CDMA communication system against narrow-band interference can be improved by using the interference suppression techniques [2–8]. Among the techniques which have been proposed in recent years there is a general method of transform-domain processing. In recent years, several authors have proposed the use of different transforms such as discrete Fourier Transform (DFT) and Karhaunen Loeve Transform (KLT) in the receiver [8] for narrow-band interference suppression.

A group of methods which are recently suggested for mitigating multi-user and intersymbol interference is based on pre-processing techniques [9–12]. In this paper, we use the pre-processing technique in unitary transform-domain in transmitter in order to narrow-band interference suppression in CDMA communication systems. In other hand, it is shown that by using the suitable processing in transmitter, the capability of mitigation of both types of interference (i.e., NBI and MAI) in CDMA systems are enhanced. As a result after applying this method, receiver complexity is reduced; because the major part of the processing which is needed to the suppression of the narrow-band interference would be shifted from receiver to transmitter.

The general structure of proposed methods in this paper is shown in Fig. 1, where the data to be transmitted is given by the vector $\boldsymbol{a}$, while the channel input is denoted as $\boldsymbol{x}$. $\mathbf{H}$ and $\mathbf{F}_{RX}$ denotes the channel matrix, and additional receiver processing, respectively. The goal is making $\mathbf{F}_{RX}$ as simple as possible and transferring complexity from receiver to transmitter. In the contrast to the detection methods, now the channel state information (CSI) is required at the transmitter side. This is naturally the case in symmetric time-division-duplex systems, where each receiver in turn also acts as transmitter [9–12].

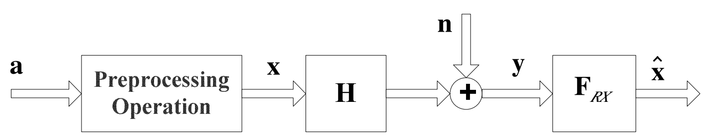

Figure 1. Diagram of a communication system with preprocessing in transmitter.

In this paper, in order to narrow-band interference suppression in CDMA communication systems, we propose two pre-processing based methods in unitary transform-domain, in which by using Karhaunen Loeve Transform (KLT) and Discrete Fourier Transform (DFT), the energy of the transmitted signal is set to zero in spectrum band where the narrow-band interference exists. The results of our simulations show that because of not sending the energy in the area where the NBI presents, any information is not deleted by NBI through channel.

Following this introduction, Section 2 describes the system model. In Section 3, the proposed narrow-band interference suppression methods are introduced. In Section 4, the receiver structure is presented. Simulation results for performance evaluation and comparison of proposed methods is given in Section 5, and the finally we present the conclusions in Section 6.

2. SYSTEM MODEL

Consider a synchronous multi-user system with K users sharing the channel, the received base-band signal in an additive white Gaussian noise channel can be modeled as:

$$r(t) = x(t) + n(t) \qquad 0 \leq t \leq T_b \tag{1}$$

where $n(t)$ represents additive white Gaussian noise of two sided power spectral density (p. s. d) σ^2, T_b is the bit duration and $x(t)$ is the transmitted signal specified by

$$x(t) = \sum_{k=1}^{K} A_k S_k(t) b_k = \mathbf{S^T}(t)\mathbf{Ab} \tag{2}$$

where $\mathbf{S}(t) = [S_1(t), \ldots, S_K(t)]$ is the vector of signature waveforms. $\mathbf{A} = \operatorname{diag}(A_i)$ is the diagonal matrix of amplitudes and $\mathbf{b} = [b_1, b_2, \ldots, b_K]$ represents the vector of the data bits of K users, such that $b_k \in \{-1, 1\}$, $k = \{1, 2, \ldots, K\}$. It is assumed that signature waveforms have unit energy. It is easy to check that the likelihood function depends on the observation only through the outputs of the bank of matched-filters matched to the signature waveforms [1],

$$y_k = \int_0^{T_b} r_k(t) S_k(t) dt \quad k = 1, 2, \ldots, K \tag{3}$$

By combining match-filter outputs from K receiving sites into a single vector, $\mathbf{y} = [y_1, \ldots, y_k]$, we get

$$\mathbf{y} = \mathbf{RAb} + \mathbf{n} \tag{4}$$

where $\mathbf{R}$ is a positive semi definite cross correlation matrix with elements R_{ij} defined as:

$$R_{ij} = \int_0^{T_b} S_i(t) S_j(t) dt \tag{5}$$

And $\mathbf{n}$ is a zero-mean Gaussian noise vector, defined as [1]

$$\mathbf{n} = [n_1, \ldots, n_k] \tag{6}$$

$$n_k = \int_0^{T} n(t) S_k(t) dt \tag{7}$$

3. PREPROCESSING IN TRANSMITTER TO MITIGATE NBI

In this paper, we propose two pre-processing based methods in unitary transform-domain for narrow-band interference rejection in direct-sequence code-division multiple access (DS-CDMA) systems. On the other hand, in order to mitigate multi-user interference, the decorrelating precoder is applied, that is defined by linear transformation matrix $\mathbf{T} = \mathbf{R}^{-1}$ [10].

3.1. The First Proposed Method

In the first proposed method, in order to NBI suppression and receiver operation simplification, energy of transmitted signal is set to zero in spectrum band where NBI exists. Discrete Fourier transform is used to determine spectrum interval occupied by NBI in transmitter. Then, spectrum bands whose amplitudes of Fourier transform are greater than 5 times of their mean, are considered as interfered band and the energy of transmitted signal is set to zero in those bands [2]. Any information is not deleted by NBI in channel because the energy of the transmitted signal in the area where the NBI presents, have been become zero in the transmitter. Hence, NBI can be rejected by using a very simple filtering operation in the receiver and there is no need to compensate those parts of signal deleted by interference. The main advantage of this method is that it can be applied to several narrow-band interference signals simultaneously.

3.2. The Second Proposed Method

In the second method, by using the Karhaunen-Loeve transform [8], the energy of the narrow-band interference is packed on to fewest number of basis vectors and similar to the first method, deletion of information by interference through channel is prevented with making zero energy of transmitted signal in spectrum band where NBI exists. Information signal is processed by the optimum transform (KLT) at the transmitter. The optimum transform (KLT) requires the knowledge of the statistical autocorrelation matrix of the narrow-band interference signal, which can be estimated in symmetric time-division-duplex systems. Therefore, the KLT can be found by estimation of the autocorrelation matrix eigenvectors of the narrow-band interference [8].

In this method, similar to the first method, in order to determine eigenvectors occupied by the narrow-band interference, we calculate the mean of received signal through return channel into the direction of eigenvectors at the transmitter, the components of transformed signal whose amplitudes are greater than 5 times of their mean are considered as interfered vectors. Then, the energy of transmitted signal is set to zero into the direction of those vectors at the transmitter. The advantage of this method, similar to the first method, is its simultaneously resistibility against several narrow-band interference signals.

On the other hand, because of the area where occupied by the narrow-band interference is estimated properly in this method [8], it is expected that its performance has been much better than that of the first method.

4. RECEIVER STRUCTURE

The receiver structure is depicted in a Fig. 2. First, the received signal is processed by Discrete Fourier Transform DFT, and then a clipping operation is performed on the transformed signal in order to reject the narrow-band interference in frequency-domain. Finally, the Inverse Discrete Fourier Transform IDFT reproduces the interference-free signal. In principle, transforming the received signal enables straightforward identification of the narrow-band interference and then

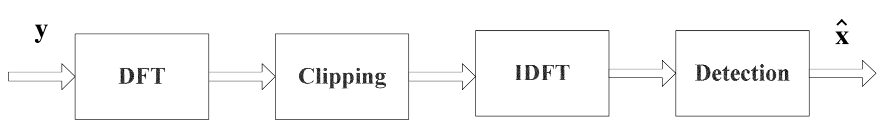

Figure 2. Block diagram of the receiver in the proposed methods.

its removal by clipping operation. The clipping operation is performed in spectrum bands whose amplitudes of Discrete Fourier Transform (DFT) are greater than 5 times of their mean. Note that the clipping operation in the receiver, does not affect on the transmitted signal, because the pre-processing operation is applied in the transmitter.

In the following section, we evaluate the performance of the proposed rejection methods in the presence of the narrow-band interference by simulations.

5. SIMULATION RESULTS

In our simulation, a digital DS-CDMA network with 3 users is considered, and GOLD sequences of length $L = 7$ are used for spreading as follows,

$$\mathbf{S}_1 = [0 \quad 1 \quad 1 \quad 0 \quad 1 \quad 0 \quad 0] \tag{8}$$
$$\mathbf{S}_2 = [0 \quad 1 \quad 0 \quad 1 \quad 0 \quad 0 \quad 1] \tag{9}$$
$$\mathbf{S}_3 = [1 \quad 0 \quad 1 \quad 1 \quad 1 \quad 0 \quad 1] \tag{10}$$

For performance analysis of a narrow-band interference suppression system a model for the narrow-band interference signal must be selected. In the literatures, in particular, narrow-band interference signals are mostly modeled as either a deterministic sinusoidal signal or an Auto Regressive (AR) signal [2–8]. An AR signal well capture the narrow-band characteristic of the interference signal, because a sinusoidal signal can be modeled by an AR (2) process. Furthermore, a narrow-band digital communication signal may be approximated by an AR process of sufficiently large order. In this section, for the performance evaluation, we consider a CDMA system in the presence of an AR narrow-band interference and white Gaussian noise. The AR interference was obtained by passing white noise through a second-order infinite impulse response filter with two poles in 0.9999 and it is modeled by the following regressive equation,

$$I(n) = 2(0.9999)I(n-1) - (0.9999)^2 I(n-2) + \nu(n) \tag{11}$$

where $\{\nu(n)\}$ is a white Gaussian process, and

$$E\{\nu(n)\nu(n+m)\} = c\delta(n) \tag{12}$$

And the value of c depends on the power of narrow-band interference. In order to enable a good performance evaluation for narrow-band interference suppression, we shift the frequency of the maximum power spectrum. In Fig. 3, the frequency shifted power spectrum of the AR signal defined above is depicted.

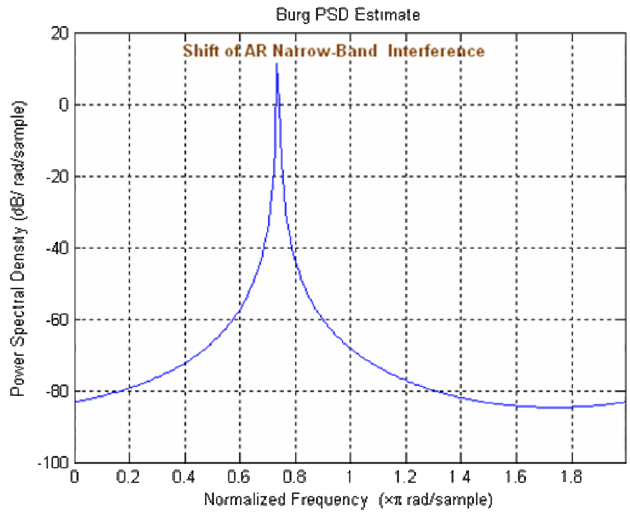

Figure 3. The shifted power spectrum of the AR narrow-band interference with two poles in 0.99999.

In order to mitigate multi-user interference a precoding technique which has been introduced in [5] and named "decorrelating precoder" is applied.

In the proposed methods, the thresholds used in notching and clipping operations are set to 5 times of the signal mean that is a typical value for this kind of systems (see [3, 4]). Figs. 4 and 5 illustrate plots of Bit Error Rate (BER) versus the desired Signal power to narrow-band Interference power Ratio (SIR) in the presence of AR, and single-tone sinusoidal NBI, respectively. In all the cases, the desired Signal power to additive white Gaussian Noise Power (SNR), E_b/N_0 (dB) is fixed to 12 dB. As it can be observed, the performance of the receiver in the presence of NBI by using the pre-processing at the transmitter is significantly improved. Comparison between two proposed methods shows that the KLT based method presents much better performance than the DFT-based method. This is because in the KLT-based method, the area where occupied by the NBI is determined by using KLT that is the optimum unitary transform in the sense of efficient packing of the energy of narrow-band signal in the presence of white noise [4]. Hence, as it is shown in simulation results, the pre-processing with KLT results is better performance than pre-processing with DFT. Note that, the price paid for the considerably improved performance in the KLT-based method, is higher computational complexity, because

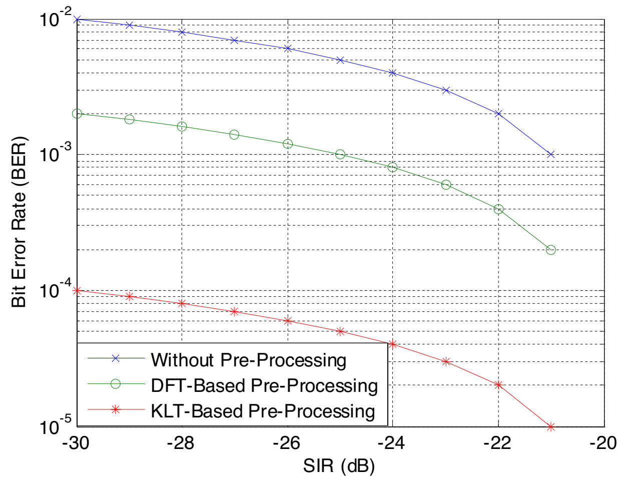

Figure 4. Bit error rate versus SIR in the presence of AR interference.

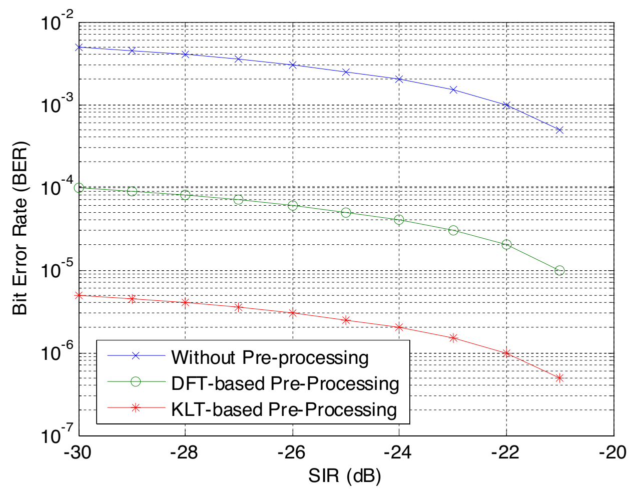

Figure 5. Bit error rate versus SIR in the presence of single-tone sinusoidal interference.

the KLT depends on the auto-correlation matrix of the NBI. Since necessary processing performs at the transmitter or the base station, high complexity of this method does not make restriction on its application.

6. CONCLUSIONS

In this paper, it has been shown that the pre-processing based technique which had been previously applied to multi-user and intersymbol interference suppression can be also applied to narrow-band interference rejection in CDMA communication systems. Hence, we have proposed two methods using pre-processing based technique in transform-domain for narrow-band interference suppression, in which the energy of the transmitted signal is set to zero in the area where the NBI presents. It is observed that the proposed methods improve the performance of the CDMA communication systems in the presence of NBI. By means of pre-processing, receiver complexity is shifted from receiver to transmitter. In this paper, it has been shown that the complexity of the DFT-based method is lower than the KLT-based method, but the system performance by using the KLT is improved more than that of by using the DFT. This is because the spectrum band where the narrow-band interference exists is determined better by using the KLT in the transmitter.

REFERENCES

1. Zigangirov, K. S., *Theory of Code Division Multiple Access Communication*, IEEE Press, 2004.
2. Milstein, L. B. and R. A. Iltis, "Signal processing for interference rejection in spread spectrum communications," *IEEE ASSP Magazine*, 18–31, April 1986.
3. Ricci, M. and G. Tulino, "Narrow-band interference suppression in multiuser CDMA systems," *IEEE Trans. on Com.*, Vol. 46, No. 6, 1163–1175, Sep. 1998.
4. Jones, W. W. and K. R. Jones, "Narrow-band interference suppression using filter bank synthesis/analysis techniques," *Proc. MILCOM 92*, 898–902, Oct. 1992.
5. Akansu, A. N., M. V. Tazebay, M. J. Medley, and P. K. Das, "Wavelet and subband transforms: Fundamentals and communication applications," *IEEE Com. Mag.*, 104–115, Dec. 1997.
6. Tazebay, M. V. and A. N. Akansu, "A performance analysis of interference excision techniques in direct-sequence spread-spectrum communication," *IEEE Trans. Signal Proc.*, Vol. 46, No. 9, 2530–2535, Sept. 1998.
7. Tay, J. and J. Nan, "Narrow-band interference rejection in DS/CDMA systems using adaptive based nonlinear ACM

interpolator," *IEEE Trans. on Vehicular Tech.*, Vol. 52, No. 1, 374–379, March 2003.

8. Azmi, P., "Narrow-band interference suppression CDMA spread-spectrum communication systems based on sub-optimum unitary transforms," *IEICE Trans. Communication*, Vol. E85-B, No. 1, 239–246, January 2002.
9. Windpassinger, C., "Detection and precoding for multiple input multiple output channel," M.Sc. Thesis, Erlangen, 2004.
10. Brandt-Pearce, M. and A. Dharap, "Transmitter-based multiuser interference rejection for the down-link of a wireless CDMA system in a multipath environment," *IEEE Journal of Selected Area on Com.*, Vol. 18, No. 3, 407–417, March 2000.
11. Wang, Z., S. Zhou, and G. B. Giannakis, "Joint coding–precoding with low-complexity turbo-decoding," *IEEE Trans. on Wireless Communication*, Vol. 3, 832–842, May 2004.
12. Vojcic, B. R., "Transmitter precoding in multiuser communications," *Proc. 1995 IEEE IT Workshop on Information Theory, Multiple Access and Queueing Theory*, St. Louis, MO, April 19–21, 1995.