“Issues and Performance Study of Jammer Suppression in Direct Sequence Spread Spectrum Communications using Fast ICA”

D.P.Acharya, G.Panda and Y.V.S.Lakshmi,

Department of Electronics & Communication Engineering, NIT, Rourkela -769 008.
Center for Development of Telematics, Bangalore – 560 100.

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d_p_acharya@rediffmail.com ,
ganapati.panda@gmail.com,
lakshmi@cdotb.ernet.in

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[1]D.P.Acharya, [1]G.Panda, [2]Y.V.S.Lakshmi
[1]Department of Electronics & Communication Engineering, NIT, Rourkela -769 008.
[2]Center for Development of Telematics, Bangalore – 560 100.
d_p_acharya@rediffmail.com , ganapati.panda@gmail.com, lakshmi@cdotb.ernet.in

***Abstract*-Independent Component Analysis (ICA) technique separates mixed signals blindly without any information of mixing system. The present work studies and analyses the issues involved in interference rejection in direct sequence spread spectrum communication systems based on Independent Component Analysis technique. The ICA technique tries to separate the unwanted interfering signal from the desired signal so that contamination of the desired spread spectrum signal is minimized. The effect of the inherent ambiguities of ICA on this model is also analyzed. Results of the simulation study carried out on the ICA assisted jammer mitigation for spread spectrum communication is presented in this work.**

I. INTRODUCTION

Spread spectrum communications, with its inherent interference attenuation capability, has over the years become an increasingly popular technique for use in diversity of systems. The systems range from antijam systems for military wireless communications to code division multiple access systems for commercial mobile communication, to systems designed to combat multipath. The properties such as antijamming, antiinterference, low probability of intercept, multiple user random access communications with selective addressing capability, high resolution ranging and accurate universal timing have made it so popular. In Direct Sequence Spread Spectrum (DS-SS) communications, the bandwidth of the transmitted waveform is intentionally made wider than would be necessary to transmit the information over the channel, by means of a code which is independent of the data. The data at the receiver end is despreaded and recovered by the same code being available at the receiver. The ratio of transmission and data bandwidth is called the processing gain and provides the system with a high degree of interference suppression capability. In most of the cases this gain is sufficient for the system's proper performance. However sometimes, additional interference suppression capability is needed due to limited availability of the bandwidth. Therefore, signal processing techniques have been used in addition to the DS spread spectrum receiver to enhance the processing gain, providing greater interference suppression without an increase in bandwidth [1]. Traditionally filters are designed as a preprocessing step to suppress the interference and increase the signal-to-noise ratio at the correlator output of the receiver. Belouchrani and Amin [2] have proposed the interference mitigation scheme using blind source separation to aid conventional detection in spread spectrum receiver. They have used second order statistics based BSS technique to separate a set of independent information signals from their mixtures observed at the sensors. However second order temporal statistics makes the scheme vulnerable to signals having low temporal correlations.

Independent Component Analysis (ICA) is a statistical signal processing technique having emerging new practical application areas, such as blind separation of mixed voices or images, analysis of several types of data or feature extraction [3],[4]. Use of ICA exploits higher order statistics and hence higher order decorrelation is achieved. ICA has been used for jammer suppression in DS-CDMA arrays in [5]. In the present work we carry out simulation study for jammer suppression by using fast ICA algorithm [6] for Direct Sequence Spread Spectrum system. We also discuss the issues involved in this technique due to the uncertainty of ICA.

II. INDEPENDENT COMPONENT ANALYSIS (ICA)

Independent Component Analysis (ICA) is a computationally efficient statistical signal processing technique for revealing hidden factors that underlie sets of random variables, measurements or signals. A generative model for the observed multivariable data, which is typically given as a large database of samples is defined by ICA. The data variables in the model are assumed to be linear or non-linear mixtures of some unknown latent variables and the system of mixing is unknown. The extraction of source in this process is done based on the assumption that the latent variables are non-Gaussian and statistically independent [7].

Suppose a set of observations of random variables is $x(t) = [x_1(t)\ x_2(t) ... x_n(t)]^T$ where 't' is the time or the sample index and they are generated from a linear mixture of sources $s(t) = [s_1(t)\ s_2(t) ... s_n(t)]^T$ that are statistically independent. Here ^{T} stands for the transpose of a matrix .The ICA model is expressed in the following form

$$x(t) = As(t) + n(t) \quad (1)$$

where A is some unknown mixing matrix and $n(t)$ is the additive noise vector at instant *t*.

Independent Component Analysis estimates both A and '$s_i(t)$' when only the observation '$x_i(t)$' are at hand. Number of independent components here is assumed to be equal to the number of observed mixtures. The ICA problem is blind because not only the signals but also the mixing coefficients are unknown.

Fast ICA Algorithm:

One of the most primary solution for linear ICA/BSS problem is Fast ICA [6] due to its simplicity and fast convergence. The basic algorithm involves the preprocessing and a fixed-point iteration scheme for one unit.

Preprocessing:

1. Center the data X to make the mean zero. This is done by subtracting the mean from the data.

2. Whiten the data to give Z. The covariance matrix of centered X is computed and then eigen value decomposition of the covariance matrix is performed. If D is the eigen value matrix and E is the eigenvector matrix then

$$Z = D^{-1/2} * E^T * Centered\ \ X \quad (2)$$

Fixed-point Iteration for one unit:

The fast ICA algorithm for one unit estimates one row of the demixing matrix W as a vector w^T that is an extremum of contrast functions whose derivatives are stated in (4)-(5). Estimation of w proceeds iteratively with following steps until a convergence as stated below is achieved.

1) Choose an initial random vector w of unit norm.

2) $w \leftarrow E\{zg(w^T z)\} - E\{g^{'}(w^T z)\}w$ (3)

where $g_1(y) = y^3$ (derivative of *kurtosis*), (4)

$g_2(y) = tanh(ay)$, $1 \le a \le 2$, (5)

and g'(y) are the corresponding derivatives.

3) $w \leftarrow w / \| w \|$ where $\|w\|$ is the norm of w. (6)

4) if $|w(old) - w(new)| \le \varepsilon$ is not satisfied then go back to step 4 where ε is a convergence parameter ($\sim 10^{-4}$) and w(*old*) is the value of w before it's replacement by the newly calculated value w(*new*).

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III. System Model & Scheme of Mitigation

We consider a DS-SS system which uses binary phase shift keying (BPSK) for both chip and data modulation. Fig 1 shows the simple transmitter model where the incoming symbol sequence is spreaded by a pseudo random noise like (PN) bit sequence so that the bandwidth of the transmitted signal increases by a factor of the processing gain. The receiver is depicted in fig 2. The transmitted signal which passes through the AWGN channel also gets corrupted by jammer signal and is received at the receiving antenna. The received signal is despreaded and demodulated before getting integrated over the bit duration. This comprises a matched filtering operation for the DS/BPSK signal. After dispreading, the jammer energy is spread over the PN code bandwidth and the integrator acts as a narrowband filter. The full system model with transmitter, channel and receiver are shown in fig 3.

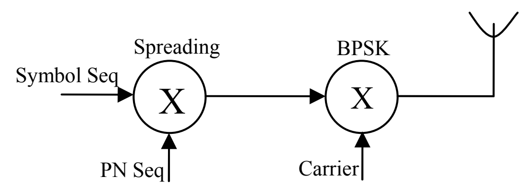

Fig. 1 DS-SS BPSK Transmitter

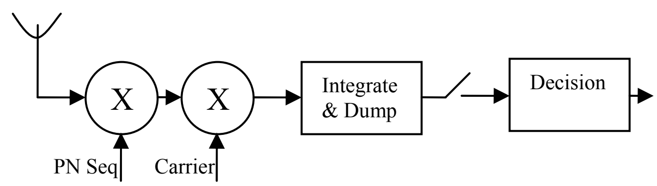

Fig.2 DS-SS BPSK Receiver

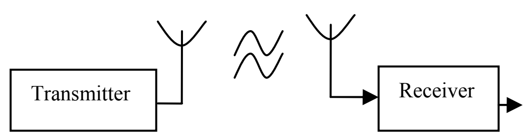

Fig. 3 Simple DS-SS System Model

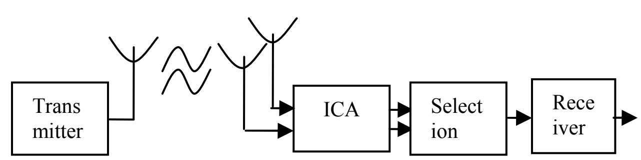

Fig. 4 ICA based DS-SS System Model

In the ICA technique for separating two signals at least two observed mixed signals are necessary. This can be achieved by having a antenna diversity at the SS receiver [7].The received signal is a mixer of the desired transmitted signal $s(t)$, jammer signal $j(t)$ and additive noise $n(t)$ in the channel. At the two receiving antenna sensors the signals $r_1(t)$ and $r_2(t)$ can be modeled as

$$[r_1(t) \quad r_2(t)]^T = A*[s(t) \quad j(t)]^T + n(t) \tag{7}$$

where A is unknown mixing matrix which depends on the channel and T denotes the transpose operator.

The baseband spread spectrum signal $s(t)$ is of the form:

$$s(t) = \sum_{k=-\infty}^{\infty} b_k m_k(t - kT) \tag{8}$$

where $m_k(t) = \sum_{l=1}^{L} c_l^k p(t-(l-1)T_c)$ with T^{-1} as the data rate, and T_c^{-1} as the chip rate. $L = T/T_c$ is the number of chips per bit called the processing gain of the SS system. $\{b_k\}$ and $\{c_l^k\}$ represent the *k*th bit data sequence and corresponding chip sequence, and $p(t)$ is the chip pulse.

The jammer signal can be continuous wave or bit pulsed. Continuous wave jammer signal is represented as

$$j(t) = \sqrt{J_p}\,\cos(wt + \phi) \tag{9}$$

where J_p is the jammer power and w is the jammer frequency and ϕ is the phase of jammer.

Assuming the waveforms $s(t)$ and $j(t)$ to be statistically independent fast ICA algorithm is performed on the received signals $r_1(t)$ and $r_2(t)$. The ICA separates the jammer and the desired signal. The ICA output signals are input to a selection block which finds the desired signal by rejecting the jammer signal. This selected desired signal is processed by the conventional receiver for detection. The demodulation process recovers the desired signal by dispreading and spreading the noise and any other interference signal which is easily filtered subsequently.

IV. Experimental Setup

In the simulation experiment study, an input symbol sequence of 10000 samples is taken. Programs for the transmitter, receiver and fast ICA algorithm are written to carry out computer simulations for the simple DS-SS system and ICA based DS-SS system as shown in fig 3 and 4 respectively. To the transmitted output signal a weighted continuous wave jammer was added. The transmitted signal is allowed to pass through a AWGN channel. A model of two antennas is considered to get the receive diversity as required for the ICA algorithm. Jammer power is changed so as to vary the jammer-to-signal ratio (SJR) in the range of -60dB to 50dB in steps of 10dB. Corresponding to each value of SJR, bit error rate (BER) at the receiver output is computed. The variation of BER with SJR at a particular signal-to-noise ratio (SNR) is studied. The experiment is conducted at SNR values 0dB and 10dB. The variation of BER with SJR is studied for the simple DS-SS system and DS-SS system with ICA assistance. The experiment is carried out for different PN sequence lengths. BER is plotted against SJR for PN sequence length 8, 16 and 32 bits.

V. Analysis of Results & Issues

The simulation studies, on both simple DS-SS and DS-SS with ICA are performed as described in the previous section. Fig 5, fig 6 and fig 7 depict the plot of BER against SJR with PN sequence lengths 8, 16 and 32 bits respectively. In case of simple DS-SS system the BER is observed to decrease with increasing SJR. At higher values of SJR, BER remains almost constant at a very low value. As the length of PN sequence increases, the BER value saturates to very low value. When ICA is used for jammer mitigation the low saturated value of BER is observed at lesser SJR values entire range of the SJR

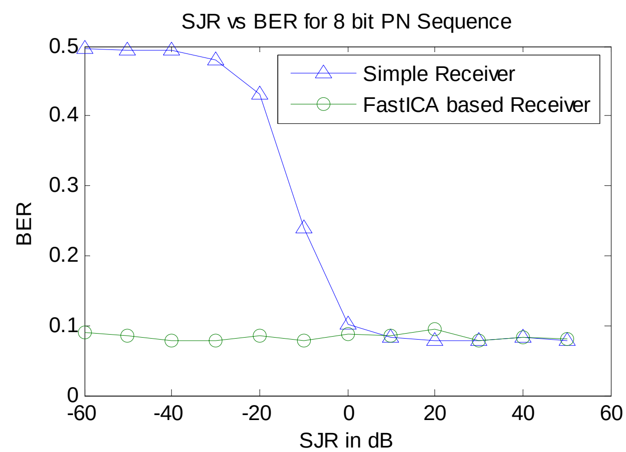

Fig 5 (Plot of SJR vs BER without and with Fast ICA for DS-SS System with 8 bits PN Sequence)

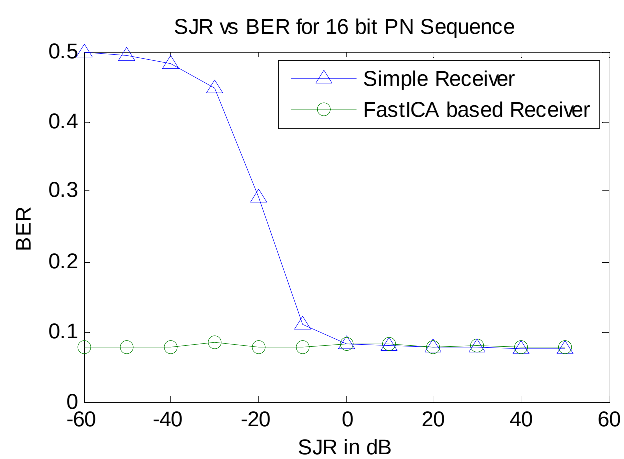

Fig.6 (Plot of SJR vs BER without and with Fast ICA for DS-SS System with 16 bits PN Sequence)

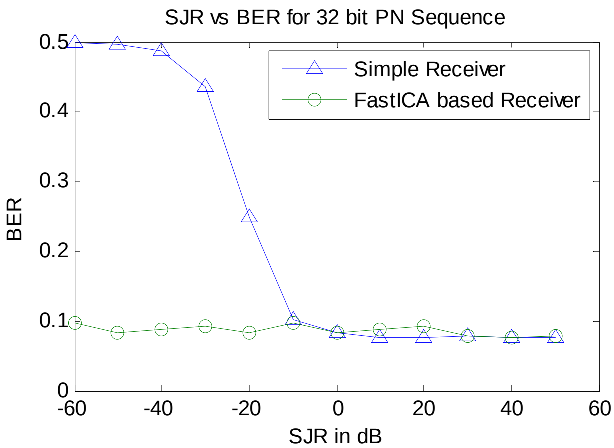

Fig.7 (Plot of SJR vs BER without and with Fast ICA for DS-SS System with 32 bits PN Sequence)

variation. This means at higher jammer powers also the ICA assisted receiver offers better BER values irrespective of the PN sequence length.

The main advantage of this ICA assisted technique is that the separation is unaffected by errors in the propagation model or any array calibration. All the above results are obtained at SNR 0dB. The same experiments when conducted at 10dB SNR always result in the lower saturated values of BER irrespective of jammer power.

However there are certain issues pertaining to the ICA assisted DS-SS technique. ICA is reported to have inherent ambiguities like permutation and scaling. Due to the permutation uncertainty the independent components recovered do not appear in a known or particular order. So at the output of the ICA block it is difficult to recognize the spread spectrum signal and jammer signal. To recognize this and get the desired spread spectrum signal, a training sequence is employed and another post processing block is used which performs selection of the desired spread spectrum signal. However this is a signal classification problem and makes the technique semiblind. Apart from this it adds to the computational complexity of the system. Owing to the scaling uncertainty, the desired signal becomes out-of-phase or sometimes the signal level changes. Exact signal recovery becomes difficult in such cases in the spread spectrum receiver where integration and dump block is prone to give erroneous bit recovery. This becomes problematic and poses to be a limitation in practical system implementation.

VI. Conclusions

The present paper studies the jammer mitigation in Direct Sequence Spread Spectrum communications system by using fast ICA technique. ICA assisted DS-SS model yields better BER performance even at high jammer power values. However selection of desired spread spectrum signal adds to the computational complexity and is also a general problem in signal processing which needs attention. The scaling uncertainty of the ICA algorithm also needs special attention while considering practical implementation ICA assisted spread spectrum receiver.

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