A Robust Technique for Blind Multiuser CDMA detection in Fading Channels

Dr. E.Gopalakrishna Sarma

*Professor& Principal,
M.G.College of Engineering
Trivandrum-695027
Kerala, India
egsarma@hotmail.com*

Dr.Sakuntala S. Pillai

*Dean (R&D), Mar Baselios
College of Engineering &
Technology,
Trivandrum-695015
Kerala, India
sakuntala.pillai@gmail.com*

Abstract

This paper considers the blind multiuser reception problem for Direct Sequence Code Division Multiple Access (DS-CDMA) systems. A hybrid approach to the blind reception of linear multiple-input multiple-output (MIMO) channels is taken up. We consider the problem of blind detection of multiuser CDMA signals in a space time scenario. The channel is assumed to have a small scale flat fading behaviour. A two step adaptive reception method used. The receiver has the knowledge of only the spreading code of interest. The higher order statistical (HOS) technique known as Independent Component Analysis (ICA) is employed for the signal separation. The performance of this technique in the small scale flat fading space time scenario with different types of user signature codes is analyzed through various simulations.

Keywords: *Blind adaptive detection, Minimum output energy, Independent component analysis, Blind source separation, Higher order statistics.*

1. Introduction

Blind multiuser detection for CDMA channels has been a hot topic interest for a long time. This is particularly because of two main reasons. First, in actual case, the receiver does not have any knowledge of the channel of propagation or of the signals except for the spreading codes. Second, the bandwidth available is to be better utilized, avoiding the need for any training or pilot signals. Adaptive estimation and detection algorithms offer optimal solution since they can track the variations in the environment.

Various blind multiuser detection techniques using Code Division Multiple Access implemented with DS Spread Spectrum (DS-SS) modulation are discussed in the literature [1]. Various adaptive methods are also cited for multipath cases [1] and without any channel estimation [2]. Wideband CDMA, though inherently interference limited, provides multipath diversity, high processing gain, security and the potential to increase system capacity. Space-time signal processing, allow space and time diversities to be exploited for interference mitigation and efficient spectrum utilization and can be used to estimate channel parameters for the design of efficient receivers [3]. Blind adaptive estimation and detection algorithms offer optimal solution as they can track the variations in the environment.

Independent Component Analysis (ICA) is a method based on higher order statistics for finding the underlying components from a multivariable or multidimensional statistical data. Blind Source Separation (BSS) [4], an easily optimizable ICA technique is being widely used in the De-noising Source Separation (DSS) framework. Results of Bit Error Rate (BER) analysis of RAKE receivers [4] and bio-signal analysis [5] are cited. This technique utilizing the statistical independency of the signals is a good technique for the reception of digital signals where the transmitted signals are essentially statistically independent.

The paper is organized as follows. Section 2 discusses the baseband space time CDMA system model. The ICA algorithm is brought out in section 3. Section 4 discusses the fading channel scenario. The main theme of this paper is given in section 5. The performance parameters and simulation results are discussed in section 6. The paper is concluded with section 7.

2. System Model

The baseband signals of individual users are assumed to be transmitted synchronously in additive white Gaussian channel. Consider a system with K users employing normalized spreading waveforms $s_k(t),\ k=1,\ldots K$ and transmitting sequences of Binary Phase Shift Keying (BPSK) symbols through their respective multipath channels. The transmitted baseband signal of the k^{th} user is given by [2]

$$x_k(t) = A_k \sum_{i=0}^{M-1} b_k[i]s_k(t - iT), \quad k=1,\ldots K, \tag{1}$$

where M is the number of data symbols per user per frame, T is the symbol interval, $b_k[i]\in\{+1,-1\}$ is the i^{th} symbol transmitted by the k^{th} user, and A_k the amplitude of the k^{th} user.

It is assumed that $s_k(t)$ is of unit energy, periodic and supported only in the interval $[0,T]$. It is of the form

$$s_k(t) = \sum_{j=0}^{N-1} c_{j,k}\, \psi(t - jT_c), \quad 0\leq t \leq T, \tag{2}$$

where N is the processing gain, $c_{j,k}$ is the signature sequence of the k^{th} user and ψ the normalized chip wave form of duration T/N. At the receiver an antenna array of P elements is assumed. The baseband multipath channel for k^{th} user can be modeled as the multiple-input multiple-output (MIMO) given by the impulse response

$$g_k(t) = \sum_{l=1}^{L} \underline{a}_{l,k}\, \alpha_{l,k}\, \delta(t - \tau_{l,k}), \tag{3}$$

where L is the number of paths for each user, $\alpha_{l,k}$ the complex gain, $\tau_{l,k}$ the delay for the k^{th} user and $\underline{a}_{l,k}=[\underline{a}_{l,k,1}, \underline{a}_{l,k,2}, \ldots \underline{a}_{l,k,P}]^T$ is the array response vector for the l^{th} path of the k^{th} user's signal. Here $\underline{g}_k = [\underline{g}_{1,k}, \underline{g}_{2,k}, \ldots \underline{a}_{P,k}]^T$ is a complex vector known as the *steering vector* representing the response of the channel and array to the k^{th} user's signal. The total received signal at the receive array is the superposition of the signals from all K users plus the additive noise (assuming linearly independent steering vectors).

$$\underline{r}(t) = \sum_{k=1}^{K} x_k(t) * \underline{g}_k(t) + \underline{n}(t), \tag{4}$$

$$= \sum_{i=0}^{M-1} \sum_{k=1}^{K} A_k\, b_k[i] \sum_{l=1}^{L} \underline{a}_{l,k}\, \alpha_{l,k}\, s_k(t - iT - \tau_{l,k}) + \underline{n}(t), \tag{5}$$

where * denote convolution and $\underline{n}(t)=[n_1(t), n_2(t), \ldots n_P(t)]^T$ is a vector of independent zero mean complex white Gaussian process with power spectral density σ^2.

A sufficient statistic for the reception of the above model is got by passing $r(t)$ through KL beamformers (spatial RAKE) followed by an array of temporal matched filters (RAKE). This scheme is equivalent to a *Space Time Matched Filter* [1].

In this model we assume time invariant delay (over N symbols), the use of discard prefix or the guard chips for ISI free chips and the absence of pilot or training sequence.

3. The ICA Method

Blind algorithms are based on higher-order statistics (HOS), which retain the phase information and allow for identifying both minimum and non-minimum phase channels. In the time domain, HOS is represented by higher-than-second-order cumulants or moments and in frequency-domain by multidimensional Fourier transforms (polyspectra and moment spectra). Algorithms using HOS exploit the non-Gaussian nature of communication signals.

Independent Component Analysis (ICA) is a non-linear, statistical computational model [4], [5] that uses linear transformations on multidimensional data to interpret the spectral signatures of the mixed signal. The technique assumes that the spectral components of the observed mixed signal are statistically independent and provides an unsupervised method for the blind source separation problem.

Given a set of observations of random variables $(y_1(t), y_2(t), \ldots y_n(t))$ where t is the time or sample index, assume that they are generated as a linear mixture of independent components **s**,

$$\boldsymbol{Y} = \boldsymbol{H}\boldsymbol{s} \tag{6}$$

where $\boldsymbol{H}$ is some unknown matrix and $\boldsymbol{Y}$ the observation vector. Signal recovery now consists of estimating both the matrix $\boldsymbol{H}$ and the $s_i(t)$, when we only observe the $y_i(t)$. The number of independent components $s_i(t)$ is taken equal to the number of observed variables; a simplifying assumption that is not completely necessary.

Alternatively, we can represent this as

$$\boldsymbol{Z}=\boldsymbol{WY}=\boldsymbol{WHs} \quad (7)$$

which indicates that estimation of ***H*** gives ***W*** by taking its inverse. The model in (7) can be estimated if and only if the components are non-Gaussian [5]. ***Z*** is the output vector, an estimate of the possibly scaled and permutated source. This corresponds to ***Z*** expressed as

$$\boldsymbol{Z}=\boldsymbol{WY}=\boldsymbol{WHs} \rightarrow \boldsymbol{DPs} \quad (8)$$

where ***D*** is a nonsingular diagonal matrix and ***P*** is a permutation matrix. At most one source is allowed to be Gaussian, to ensure the identifiability. The solution of this BSS problem is based on maximum-likelihood estimation, minimization of mutual information, or infomax [6].

In Multiple Input Multiple Output (MIMO) channels BSS tries to estimate the unobservable sources, the mixing or its inverse system, without explicit knowledge of the system or signals.

4. Fading Channels

Author Radio waves propagate from a transmitting antenna, and travel through free space undergoing absorption, reflection, refraction, diffraction, and scattering. In the absence of any *line-of-sight* path between the transmitter and the receiver, propagation is mainly due to reflection and scattering resulting in the transmitted signal arriving at the receiver via several paths with different time delays creating a *multipath* situation. At the receiver, the multipath waves with randomly distributed amplitudes and phases combine to give a resultant signal that fluctuates in time and space generally termed as *fading*. The short-term fluctuation in the signal amplitude caused by the local multipath is called *small-scale fading,* and is observed over distances of about half a wavelength. On the other hand, long-term variation in the mean signal level is called *large-scale fading or shadowing.* Small-scale fading can be further classified as flat or frequency selective, and slow or fast. A *flat fading* radio channel has a constant gain and a linear phase response over a bandwidth larger than the bandwidth of the transmitted signal. On the other hand a smaller channel bandwidth leads to time dispersion of the transmitted symbols within the channel (*frequency selective fading)* and results in *intersymbol interference* (ISI). For a significant Doppler spread relative to the bandwidth of the transmitted signal, the received signal is undergoes *fast fading,* otherwise a *slow fading* occurs.

In *Rayleigh fading* the mobile antenna, instead of receiving the signal over one line-of-sight path, receives a number of reflected and scattered waves, and in *Rician Fading,* in addition to the multipath components, there exists a direct path between the transmitter and the receiver. The probability density functions (pdf) of the received signal envelope, f(r) for these are given below.

For Rayleigh,

$$f(r)=\frac{r}{\sigma^2}\exp\left\{-\frac{r^2}{2\sigma^2}\right\}, \qquad r \geq 0$$

and for Rician,

$$f(r) = \frac{r}{\sigma^2} \exp\left\{-\frac{r^2 + k_d^{\ 2}}{2\sigma^2}\right\} I_o\left(\frac{rk_d}{\sigma^2}\right), \qquad r \geq 0$$

where $I_0(\ )$ is the 0^{th} order modified Bessel function of the first kind and $\boldsymbol{\sigma}^2$ the variance. *K* is the Rician factor, defined as the ratio between the deterministic signal power (from the direct path) and the diffuse signal power (from the indirect paths). Figure 1 shows the two distributions.

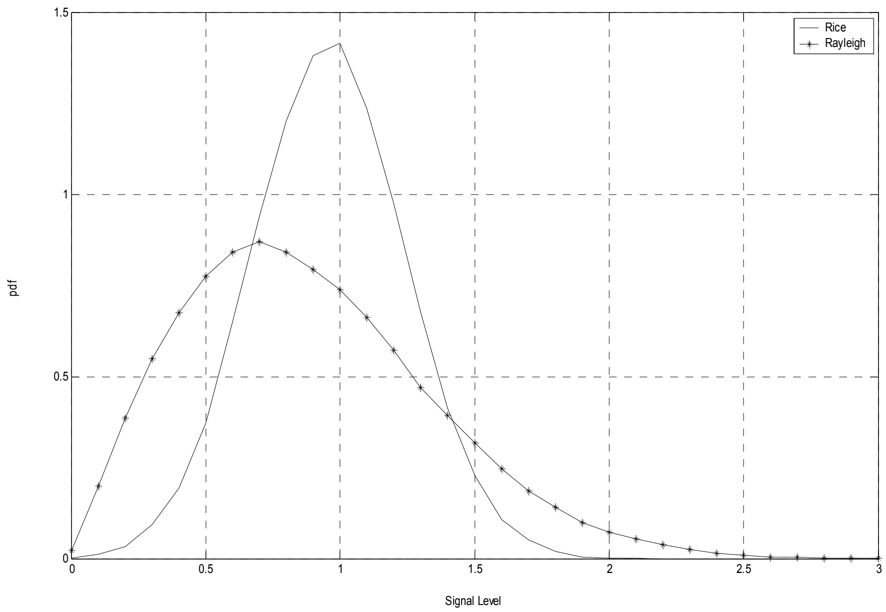

Figure 1

5. Proposed Blind MUD in Fading channels

The In multiuser CDMA each complex message bit is coded into bit streams using the unique user signature, and transmitted through the channel, where they get mixed with the signals of the other signals and also with some noise caused by multi-path propagation, Doppler shifts, interfering impulsive signals and the like. At the receiver we have only the mixed noisy signal and the signature sequence(s). First, the sources are separated using the ICA method [9],[10],[11] to retrieve the bit streams (mutilated by the channel). Second, the required user signal is taken out and the bit streams detected to recover the original message.

At the l^{th} antenna the signal with interference and ambient noise is given by

$$y_l = \underline{g}_l \sum^{M-1} \sum^{K} A_k\, b_k[i]\, s_k(t - iT) + n'(t), \qquad (9)$$

i=0 k=1

where g_l approximates the overall effect of various user-antenna paths, and *n'(t)* the associated noise. In matrix form we can have the model representation repeated as in (6).

$$\boldsymbol{Y} = \boldsymbol{Hs} \quad (10)$$

Here ***Y*** is the $L \times M$ matrix, each row giving the stream at each antenna, ***H*** the $(L \times L)$ transfer matrix (steering vector) of the multipath channel. Each row of the $L \times M$ matrix ***s*** gives the combined effect of all users' signals. These row signals will be independent since they are being formed in transit over different independent paths and time with entirely different mixing properties [12],[13],[14].

The detection of the desired user is done through an adaptive MUD algorithm [7] based on decomposing the linear MUD filter response (canonical representation) into two orthogonal components, one being equal to the signature waveform of the desired user. Consider the linear detector of user1 characterized by the filter response c1, the symbol estimate is

$$\text{b\_hat1}=\text{sgn}(\langle y,c \rangle) \quad (11)$$

where $c1=s_1+x_1$ and $\langle s_1,c_1 \rangle=0$

Here s1 is the signature waveform of user1 which is known. The orthogonal component of the given linear transformation d_1 is given by

$$x_1=(1/\langle s_1,d_1 \rangle)*d_1-s_1 \quad (12)$$

Thus we have, $\text{b\_hat1}= \text{sgn}(\langle y, s_1+x_1 \rangle)$ (13)

$$\text{b\_hat1}=\text{sgn}(A_1b_1+ \sum_{k=2}^{K} A_kb_k(\rho_{1k}+ \langle s_k,x_1 \rangle)+n_1 \quad (14)$$

where ρ_{1k} is the cross-correlation of the signature sequences of the users. Choosing x1 to minimize the output energy would just minimize the interference energy. The output energy of this *minimum output energy* (MOE) detector is

$$\text{MOE}(x_1)=E\{(\langle y,s_1+x_1 \rangle)^2\} \quad (15)$$

The Mean Square Energy (MSE) is

$$\text{MSE}(x_1)=E\{(A_1b_1-\langle y,s_1+x_1 \rangle)^2\} \quad (16)$$

It is seen that minimizing (17) and (18) differs only by a constant. Thus we have an adaptive MMSE detector without the need for any training sequence (since the MOE does not depend on the data). The steepest descent algorithm is used to derive the update rule for the adaptive algorithm. We just need to update the orthogonal component to s_1 since we are trying to obtain the minimum of the MOE by changing just x_1.

The update rule is given by

$$x_1[i]=x_1[i-1]-\mu Z[i](y[i]-Z_{mf}[i]s_1) \quad (17)$$

where Z_{mf} is the matched filter estimate of the symbol concerned and μ the step size.

6. Performance Evaluation

The simple 3-user scenario in the Gaussian and (Rayleigh) fading channels is considered. Random sequences of antipodal signals are generated for each user. For the source separation a random transfer matrix is created and updated adaptively (prior to the start of transmission) till weight updating is converged. Distinct Gold sequences of length N = 31 are used as spreading code for each user. The conventional and the proposed adaptive detectors are evaluated for the average Bit Error Rate (BER) versus Signal-to-Noise Ratio, BER versus Near Far Ratio (NFR) and Error convergence.

Figure 2 shows the system set up used for the simulations.

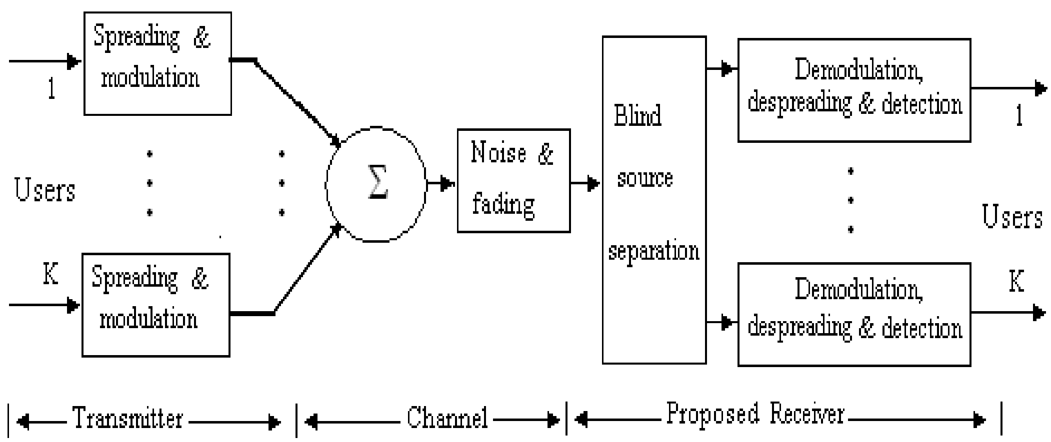

Figure 2

Figure 3 gives the simulation results of the BER simulation for varying number of users with Gold spreading codes in the Rayleigh fading channel.

Figure 4 shows NFR performance of the proposed scheme in the Rayleigh fading MIMO scenario. This is obtained as the BER versus near-far ratio (NFR) plot for a fixed SNR (10 dB in this simulation). Here also the matched filter is taken as the reference.

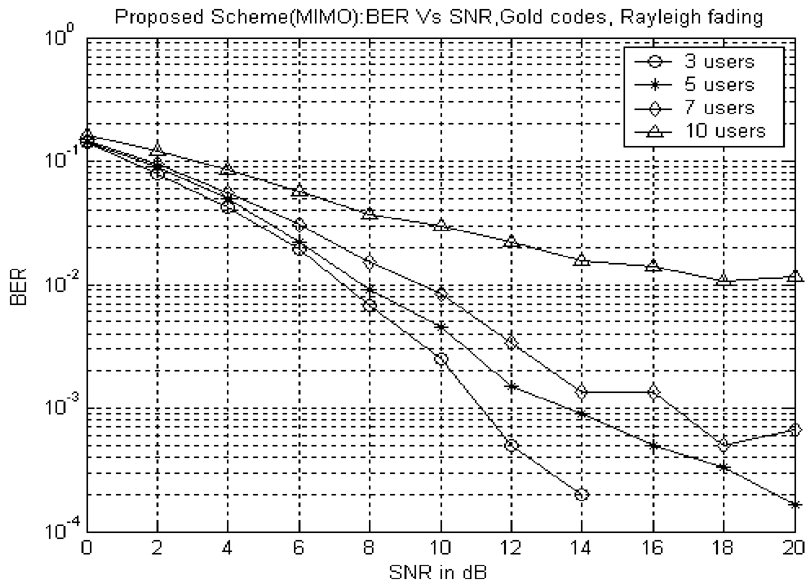

Figure 3

Figure 5 shows the convergence performance of the proposed (MIMO) adaptive scheme in comparison to the conventional detection method. The MMSE detector is taken as a reference for comparison.

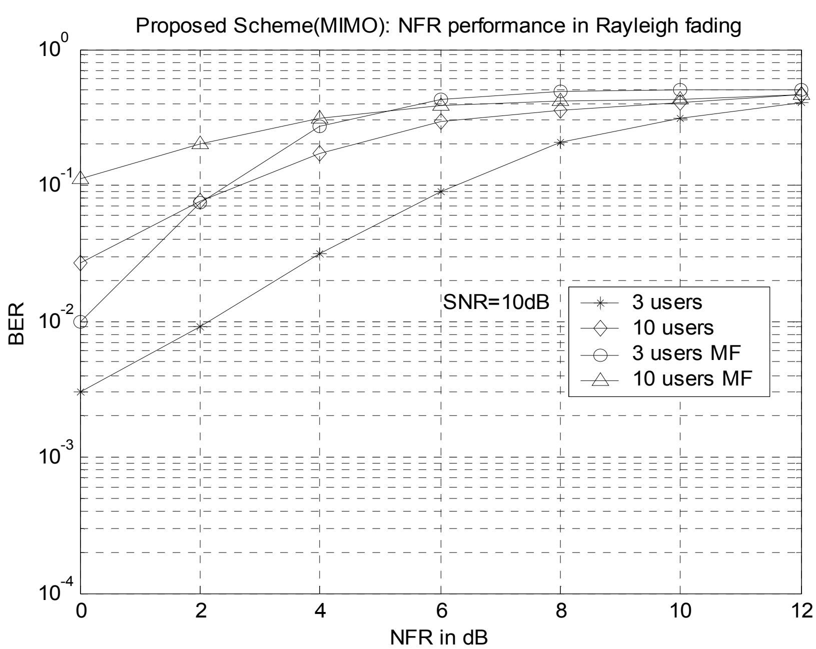

Figure 4

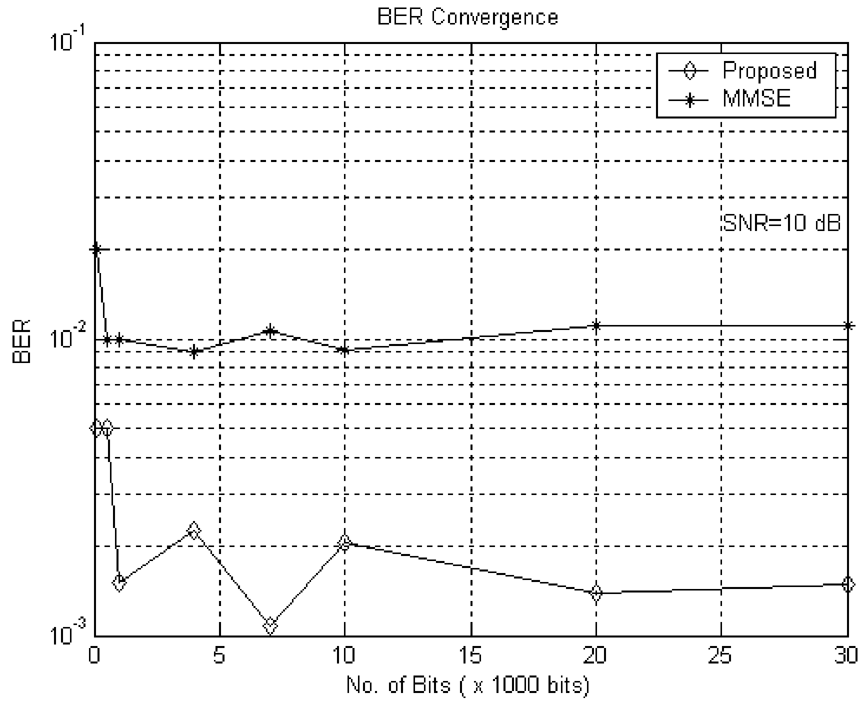

Figure 5

7. Conclusion

This paper considered a two-step method for the blind reception of Space Time Multiuser DS-CDMA signals in fading channels. The novelty and robustness of this adaptive approach consist in replacing the estimation that is large and computationally demanding. This robust technique saves much of time and bandwidth to be of great use in wideband applications.

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Authors

Dr.E.Gopalakrishna Sarma obtained his BSc (Engg) (Electronics and communication, 1983), MTech (Applied electronics & Instrumentation, 1995) and PhD in Wireless Communication (2010) from University of Kerala. He also got MBA (1998) and Advanced Diploma in Computer Applications (2002) from IGNOU, New Delhi. Presently, he is working as Professor & Principal M.G.College of Engineering, Trivandrum, Kerala. He has about 27 years of professional experience in industry/research/teaching. Has industrial experience in satellite communication and broadcast studio equipments. Has many publications to his credit. His areas of interests include: spread spectrum systems, and AI.

Dr.SakuntalaS.Pillai obtained her BSc (Engg) in Telecommunications (1968), MSc (Engg) in1977 and PhD in (1989) from University of Kerala. Presently, she is working as Professor and Head, Dept of Electronics and Communication, Mar Baselios College of Engineering and Technology, Trivandrum. She has experience in teaching of 30 years, research of 15 years and administrative of 8 years. She was Director, LBSCST, Trivandrum (2002-2004). Her area of interests include: spread spectrum systems and error correcting codes.